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CHEMICAL ENGINEERING COST ESTIMATION

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BUILDING FOR THE FUTURE OF A PROFESSION

Fifteen prominent chemical engineers first met in New York more than thirty years ago to plan a continuing literature for their rapidly growing profession. From industry came such pioneer practitioners as Leo H. Baekeland, Arthur D. Little, Charles L. Reese, John V. N. Dorr, M. C. Whitaker, and R. S. McBride. From the universities came such eminent educators as William H. Walker, Alfred H. White, D. D. Jackson, J. H. James, J. F. Norris, Warren K. Lewis, and Harry A. Curtis. H. C. Parmelee, then editor of *Chemical & Metallurgical Engineering*, served as chairman and was joined subsequently by S. D. Kirkpatrick as consulting editor.

After several meetings, this Editorial Advisory Committee submitted its report to the McGraw-Hill Book Company in September, 1925. In it were detailed specifications for a correlated series of more than a dozen text and reference books, including a chemical engineers' handbook and basic textbooks on the elements and principles of chemical engineering, on industrial applications of chemical synthesis, on materials of construction, on plant design, on chemical-engineering economics. Broadly outlined, too, were plans for monographs on unit operations and processes and on other industrial subjects to be developed as the need became apparent.

From this prophetic beginning has since come the McGraw-Hill Series in Chemical Engineering, which now numbers about thirty-five books. More are always in preparation to meet the ever-growing needs of chemical engineers in education and in industry. In the aggregate these books represent the work of literally hundreds of authors, editors, and collaborators. But no small measure of credit is due the pioneering members of the original committee and those engineering educators and industrialists who have succeeded them in the task of building a permanent literature for the classical engineering profession.

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CHEMICAL ENGINEERING COST ESTIMATION

ROBERT S. ARIES

R. S. Aries & Associates
Polytechnic Institute of Brooklyn

ROBERT D. NEWTON

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New York · Toronto · London · 1955

CHEMICAL ENGINEERING COST ESTIMATION

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Library of Congress Catalog Card Number 55–6851

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FOREWORD

In or out of management, engineers and chemists are constantly serving as trusted advisers to management on economic matters. It is clear then that technical men would do well to consider how their efficiency and competence in advising management can be increased. Seldom can top management take time to master the technical details of a process or a new product and, further, top management usually does not care about such detailed information. Instead, management begins to take an active interest in the technical project when it begins to be discussed in terms of an important amount of dollars either as a continuing expense for investigation or as a capital risk of significant proportions. At this critical stage in the life of a project, either management must learn some of the technical details already well known to the engineer or chemist so that management can extract from the project reports the necessary information to prepare an economic estimate, or the engineer or chemist must learn enough of the language of business and management so that he can successfully bridge the gap between the technical details of the project and the economic factors on which management's ultimate decision must be based. It will probably be accepted as obvious by most of us that the better method is for the technically trained person to speak the language of those above him so that he can serve up to management project proposals in as nearly the form requiring a yes or no decision as possible. The "Esperanto" that can be learned by the engineer and businessman alike is *the language of dollars.*

Not many years ago the tendency was to relegate the engineer largely to the execution of purely technical work and to ask him for opinions only on the technical side of a proposal. As the chemical industry has grown, it has also become so complex that a purely business-oriented executive cannot possibly make all the decisions on expenditures necessary for continued growth and success of the business. Thus, the engineer has been called upon to fill in between the purely technical and the purely business aspects of project proposals.

We engineers are guilty of the most amateurish efforts to present the economic side of our projects. We oversimplify or we needlessly complicate, but what is even more serious, we frequently present dogmatic conclusions and recommendations based on inadequate cost estimates instead of presenting a clear-cut analysis of the economic factors involved in a project so that management, which is far better qualified to make the final decision than we, can get at the decision promptly and in a manner which will give management reassurance that its decision is the correct one. As Dr. T. K. Sherwood has said in addressing an American Institute of Chemical Engineers symposium on cost estimation, "We do not try to teach engineers management, we try to teach them perspective." Surely this is what "Chemical Engineering Cost Estimation" is principally intended to do: help the engineer give management economic perspective on a given project. Management will do the managing once it has been guided in terms of "dollar Esperanto" into possession of adequate knowledge and perspective on the proposed project.

It would be a very strange and wonderful thing if this book could convert all or a large part of engineers and chemists into expert economic advisers. However, perhaps by bringing the problem out into the open in the authors' direct any-considered-estimate-is-better-than-a-guess fashion, we can make some further headway on it.

Since Roger Williams wrote in 1950 in the original pioneer-

ing edition, "Chemical Engineering Cost Estimation," "Let us hope this forward step will lead to others—that more of the gaps will be filled," exactly what he hoped for has happened. Not only have the authors completely revised the presentation but they have extended the sections on analysis and have added to the cost-data correlations, calling on data from the many papers published since the preliminary edition. Thus, the present edition brings the estimator up to date on the main current of what has been published on cost estimating.

Grateful for this useful and extended handbook, we engineers can proceed to sharpen and extend our ability to serve up to our managements project proposals ready for yes or no answers.

C. A. Stokes
Director of Research and Development
Godfrey L. Cabot, Inc.

PREFACE

CHEMICAL plants are built to earn profits! Such a criterion should always be used as a measure of the economic attractiveness of every new venture and every change in an established enterprise. Cost estimating is the art, based upon empirical and factual relationships, of predicting the economic future of a proposed operation. It is composed of three basic phases: investment, which is the money necessary for establishing facilities for productive operations; cost, which is the expense of the effort to manufacture and sell the product; and profit, which is the excess return over cost resulting from the sale of the product. To the scientifically trained person, who has learned the use of the integral sign, the application of the Reynolds number, or the structure of the benzene ring, the mastery of the entire subject should prove to be without difficulty. Thus the engineer and chemist can visualize their technical efforts in terms of cost and profit and direct their work toward greater productivity and success.

Until the last few years very little of a quantitative nature was available on the subject of cost estimating. Fortunately this condition has changed and more factual data have been published. Certain individuals and groups deserve special mention for their pioneering efforts in providing the initial impetus for such a change: Harding Bliss for the first comprehensive cost analysis of equipment; R. A. Dickson for simplifying piping costs; John Happel for his study of capital costs; Roger Williams, Jr., for his correlation of equipment costs, and C. H. Chilton for his thorough application of the same prin-

ciples; W. L. Nelson for his extensive compilation on equipment; H. J. Lang for his mathematical analysis of capital investment; E. C. Dybdal for his study on project evaluation; the U.S. Bureau of Mines for their analysis of manufacturing expenses; O. T. Zimmerman and I. Lavine for their assembly of equipment-cost data; the editors of the magazine *Chemical Engineering* for encouraging advancement in this field and their acceptance of pertinent articles for publication; and the American Society of Mechanical Engineers, the American Institute of Chemical Engineers, and the American Chemical Society for their timely auspices for symposia on the subject of economic evaluation.

It was in an effort to help fill the need for quantitative cost information that the authors compiled five years ago the preliminary edition, "Chemical Engineering Cost Estimation," which was intended for limited circulation. So great was the demand, both in industry and universities, that its first printing was exhausted quickly, as was the second. Thus the present edition has been completely revised and brought up to date, its scope has been broadened, and extensive additions have been incorporated within the subject matter. In accomplishing this we have drawn upon the many excellent articles which have appeared on various phases of cost estimating, a large portion of which have been published in *Chemical Engineering*. It is fitting that special credit be given to those responsible for these publications since without their contributions to the field effective consolidation of this book would have been impossible.

Each chapter deals with a particular phase of cost estimating. The initial chapter deals with methods for determining capital investment. Chapter 2 provides considerable data for equipment-cost estimation, while Chap. 3 deals with the other components of physical-plant cost. Manufacturing expense is discussed in the fourth section, and this is followed by a chapter on the general expenses of running a business. Chapter 6

deals with profit and methods for its expression. The effect of plant size and of operating level is dwelt upon in the seventh section of the book. Chapter 8 is concerned with the related subject of plant location and its effect upon costs. The relative importance of the components of cost is discussed in Chap. 9. The last chapter deals with the economic evaluation of projects. Inasmuch as the purpose of this book is to show how to estimate cost, we have concentrated on providing, without undue discourse, the type of data required to accomplish this aim. The reader is referred to the bibliographies at the close of each chapter. These contain extensive listings of many excellent publications, many of which dwell in great detail upon particular phases of cost estimation.

In closing these introductory remarks, the authors would like to take this opportunity to thank the many persons whose encouragement and contributions have made this book a reality and, in particular, Rudolf M. Cziner, of R. S. Aries & Associates, for his invaluable assistance and advice in the preparation of the manuscript.

Robert S. Aries
Robert D. Newton

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1. CAPITAL INVESTMENT

CAPITAL investment is the monetary outlay required for the erection of productive facilities and their ultimate operation. There are two types of capital: fixed capital and working capital. Fixed capital represents the investment in production and auxiliary facilities. Working capital refers to the funds required for the normal conduct of business.[1,3,20] *

Table 1. Capital-investment Estimate

Fixed capital.....	$_____
Working capital.....	_____
Total capital.....	$_____

FIXED CAPITAL

About 85 to 90 per cent of total capital is comprised generally of fixed capital. Fixed capital may be defined as the total cost of processing installations, buildings, auxiliary services, and engineering involved in the creation of a new plant. Table 2 shows an outline of the details of fixed capital and its primary subdivisions.[3,7,9]

The first primary subdivision of fixed capital is the physical-plant cost, which is the sum of all equipment, material, and labor expenditures incurred in the actual construction of plant

* Superior numerals correspond to the numbered references at the end of each chapter.

facilities. The physical-plant cost plus the expense of engineering and construction comprises the direct plant cost.[10,11] The contractor's fee plus a suitable contingency added to the direct plant cost constitutes the fixed-capital cost.

Table 2. Fixed-capital Estimate

Purchased equipment	$ ———
Equipment installation	———
Piping	———
Instrumentation	———
Insulation	———
Electrical	———
Buildings	———
Land and yard improvements	———
Utilities	———
Physical-plant cost	$ ———
Engineering and construction	———
Direct plant cost	$ ———
Contractor's fee	———
Contingency	———
Fixed capital	$ ———

Engineers making economic studies are often called upon to make preliminary capital-cost estimates for processing plants. Such studies usually involve new installations for processes resulting from research and developmental work. Estimates of this type may have to be made for many projects which are never carried out, and therefore there is a practical limit to the time which may be spent in evaluation. However, since important decisions are frequently based upon such determinations, it is essential that the determinations result in the greatest accuracy consistent with the effort expended. Thus, before an estimate is undertaken, a decision must be made as to the degree of accuracy it must have, since the more precise

the evaluation, the greater the amount of work entailed. For the procedures outlined in this chapter, six different types of fixed-capital-estimating methods are described. Each is progressively simpler and requires successively less information, but with resultant decreasing accuracy.[2, 13, 14, 16, 18, 21, 24]

Fixed-capital Estimate, Method 1

This method requires the individual, independent estimation of each article of physical-plant cost as outlined in Chaps. 2 and 3. Employing the latter as a basis, the additional component required to arrive at the direct plant cost is estimated as equivalent to a percentage of physical cost. Likewise, the fixed-capital cost is determined by adding to the direct cost the additional required items evaluated as equivalent fractions of direct plant cost.

Table 3. Fixed-capital Estimate, Method 1

Purchased equipment	$
Equipment installation	
Piping	
Instrumentation	
Insulation	
Electrical	
Buildings	
Land and yard improvements	
Utilities	
Physical-plant cost	$
Engineering and construction *	
Direct plant cost	$
Contractor's fee †	
Contingency †	
Fixed capital	$

* Estimated as an equivalent percentage of physical cost.
† Estimated as an equivalent percentage of direct cost.

Engineering and Construction. The category of engineering and construction covers the cost of design, engineering, field supervision, temporary construction, and inspection. In general, it may be estimated as being equivalent to a percentage of the physical-plant cost. Table 4 lists percentage values of the physical-plant cost which may be employed in the determination of normal engineering and construction expense.[15] The values in Table 4 are for use under average conditions. For complex installations or erection under difficult conditions, engineering and construction expense will increase by one-half the amount shown.

Table 4. Cost of Engineering and Construction
(Equivalent to percentages of physical cost)

Physical cost	*Engineering and construction cost, %*
Less than $1,000,000	30
$1,000,000–$5,000,000	25
More than $5,000,000	20

Contractor's Fee. The contractor's fee depends upon the size, complexity, and location of the plant. It may be estimated as being equivalent to 4 to 10 per cent of the direct plant cost, which is the sum of the physical-plant cost and the engineering and construction expense.[15]

Contingency. In order to compensate for unpredictable expense, minor process changes, price changes, and estimating errors, a contingency charge is applied against the direct plant

Table 5. Cost of Contingency
(Equivalent to percentages of direct plant cost)

Contingency level	*Contingency cost, %*
Low	10
Average	15
High	25

cost. It may be calculated as shown in Table 5 as equivalent to a percentage of the direct plant cost. A new development where there is no previous similar experience and rather limited information will carry a high contingency, whereas a simpler installation similar to other construction will need only a minimum contingency.[15]

Fixed-capital Estimate, Method 2

The use of this method requires initially that the cost of purchased process equipment be calculated as shown in Chap. 2. All other components of physical-plant cost are then estimated individually as equivalent to percentages of the equipment cost, as indicated in Chap. 3. Additions necessary to arrive at the values of the direct plant and fixed-capital costs are computed as equal to percentages of the physical cost and direct plant

Table 6. Fixed-capital Estimate, Method 2

Purchased equipment	$ ____
Installation *	____
Piping *	____
Instrumentation *	____
Insulation *	____
Electrical *	____
Building *	____
Land and yard improvements *	____
Utilities *	____
Physical-plant cost	$ ____
Engineering and construction †	____
Direct plant cost	$ ____
Contractor's fee ‡	____
Contingency ‡	____
Fixed capital	$ ____

* Estimated as an equivalent percentage of purchased-equipment cost.
† Estimated as an equivalent percentage of physical cost.
‡ Estimated as an equivalent percentage of direct cost.

cost respectively, employing the figures presented for the use of Method 1.

Fixed-capital Estimate, Method 3

The fixed-capital cost of a plant may be estimated by multiplying the purchased cost of equipment, estimated by the same procedures used in Methods 1 and 2, by one of the three applicable factors derived by Lang. These factors, listed in Table 7, are dependent upon the physical nature of the process.[12]

$$I_F = EL$$

where I_F = fixed-capital investment
E = purchased-equipment cost
L = Lang's factor

Table 7. Lang's Factors for Fixed Capital

Process	*Factor*
Solid	3.10
Solid-fluid	3.63
Fluid	4.74

Fixed-capital Estimate, Method 4

In order to use Method 4 for fixed-capital estimation, the fixed-capital cost of a plant for the same process but of different capacity must be known. By multiplying the known fixed-capital cost by the ratio to the 0.7 power of the production capacity of the unknown to that of the known plant, the fixed-capital cost of unknown installations may be approximated.[1, 19]

$$I_{Fb} = I_{Fa}\left(\frac{r_{mb}}{r_{ma}}\right)^{0.7}$$

where r_{ma} = monthly production rate of plant a
r_{mb} = monthly production rate of plant b
I_{Fa} = fixed-capital investment of plant a
I_{Fb} = fixed-capital investment of plant b

This method is an adaptation of the six-tenths factor rule which is applied for use in estimating equipment costs as outlined in Chap. 2. A similar rule applies to fixed-capital costs, except that the absolute value of the power term is governed by the following rules:

1. For the average chemical process, the power term will be 0.7, as shown in the equation.
2. For very small installations or for processes employing extreme conditions of temperature or pressure, the value of the power term will be from 0.3 to 0.5.
3. For plants achieving higher capacities through the employment of a high proportion of multiple units rather than larger-sized equipment, the term will be 0.8.

Table 8 shows the variation in the power term for a wide variety of processes.

Table 8. Variation in Power Term for Complete Plants

Type of plant	*Power term*
Aluminum ingot	0.90
TNT	1.01
Synthetic ammonia	0.81
Styrene	0.53
Refinery	0.75
Contact sulfuric acid from smelter gas	0.91
Solvent extraction of lubricating oil	0.68
Ethylene from refinery gas	0.67
Thermafor catalytic cracking	0.71
Contact sulfuric acid from sulfur	0.63
Catalytic polymerization of refinery gas	0.66
Hypersorption	0.42
Water gas	0.81
Fischer-Tropsch	0.79
Peterson sulfuric acid towers	0.73
Soybean extraction	0.70
Butadiene from butylene	1.02
Low-purity oxygen	0.58

Fixed-capital Estimate, Method 5

Considerable data have been published on the average fixed-capital cost of chemical plants per unit of annual capacity. Employing such values as are listed in Table 9, an approximation of the fixed-capital cost may be obtained by multiplying by the annual productive capacity of the plant.[6, 22, 23]

$$I_F = i_F r_a$$

where I_F = fixed-capital investment
i_F = fixed capital per unit of annual productive capacity
r_a = annual production rate

Table 9. Fixed Capital per Annual Ton of Capacity

Type of plant	*Cost*	*Type of plant*	*Cost*
Acetaldehyde from acetylene	$ 54	Aniline from nitrobenzene	$ 320
Acetic acid from acetaldehyde	50	Butadiene from butane	1,200
Acetic anhydride from acetic acid	200	Butadiene from butylene	830
Acetonitrile from cyanohydrin	175	Butadiene from ethyl alcohol	550
Acetylene from calcium carbide	230	Butanol, synthetic	570
Acetylene via Schoch process	460	Butyl rubber	1,300
Alkyd resins	60	Calcium carbide	85
Allyl alcohol	1,950	Calcium cyanamide	70
Alumina from bauxite	100	Carbon bisulfide	100
Aluminum	600	Carbon black	120
Aluminum sulfate	12	Carbon tetrachloride	95
Ammonia	240	Cement	20
Ammonium nitrate	15	Chlorine, electrolytic	290
Ammonium phosphate	97	Chloroform from acetone	58
Ammonium sulfate	8	Dialkyl phthalates	120
		Diphenylamine	320

Table 9. Fixed Capital per Annual Ton of Capacity (*Continued*)

Type of plant	*Cost*
Disodium phosphate	$ 48
Ethanol from grain	150
Ethanol from molasses	85
Ethyl ether	40
Ethylene from refinery gas	130
Ethylene dichloride	390
Ethylene glycol	300
Formaldehyde, 37%, from methanol	18
Furfural	320
Gasoline, aviation	140
Gasoline, TCC	24
Glycerine, synthetic	620
Hydrochloric acid from salt	165
Hydrofluoric acid	210
Isopropyl alcohol	97
Lactic acid	500
Lime	6
Magnesium, electrolytic	850
Manganese, electrolytic	380
Methanol, synthetic	270
Methyl chloride from methanol	62
Methyl isobutyl ketone	60
Naphthol	350
Neoprene	1,300
Nitric acid, synthetic	165
Oxalic acid, oxidation process	$ 200
Oxygen, high-purity	120
Oxygen, low-purity	24
Paper, Kraft from pulp	140
Phenol, synthetic	440
Phenolic resin	53
Phosphoric acid, Dorr process	60
Phosphorus, electric furnace	420
Phthalic anhydride from naphthalene	340
Phthalic anhydride from xylene	600
Pulp, sulfate	220
Silicon carbide	175
Soda ash	68
Sodium	700
Sodium silicate	9
Sorbitol	1,300
Styrene	570
Sulfuric acid, contact from pyrites	40
Sulfuric acid, contact from sulfur	18
Superphosphate	15
Titanium dioxide	640
Toluene via hydroforming	310
Trichloroethylene from acetylene	120
Urea	48

Fixed-capital Estimate, Method 6

A very general approximation employed to measure the economic attractiveness of a proposal states that one dollar of capital investment should yield one dollar of annual sales value. The ratio of annual sales value to capital investment is defined as the turnover ratio.[8,17]

Table 10. Turnover Ratios for Various Chemicals

Chemical	*Turnover ratio*
Butadiene from butane	0.21
Soda ash	0.35
Ammonia	0.35
Methanol, synthetic	0.37
Chlorine and caustic, electrolytic	0.45
Sulfuric acid, contact from pyrites	0.54
Hydrochloric acid from salt	0.56
Styrene	0.61
Alumina from bauxite	0.74
Butanol	0.75
Phenol, synthetic	0.74
Cement	1.00
Ethanol from grain	1.01
Aniline from nitrobenzene	1.07
Ethylene glycol	1.11
Acetylene from calcium carbide	1.14
Nitric acid, synthetic	1.29
Acetic anhydride from acetic acid	1.39
Glycerine, synthetic	1.41
Calcium carbide	1.55
Phosphoric acid, Dorr process	1.70
Lime	1.80
Urea	2.36
Acetaldehyde from acetylene	4.16
Formaldehyde, 37%, from methanol	4.40
Ammonium sulfate	5.55
Ethyl ether	6.16
Phenolic resin	8.30

By multiplying the unit sales value by the annual capacity and dividing by the turnover ratio, the fixed-capital cost may be approximated.

$$I_F = \frac{Sr_a}{T}$$

where I_F = fixed-capital cost
S = sales value per unit of production
r_a = annual production rate
T = turnover ratio

Examples of turnover ratios for a number of different chemicals are shown in Table 10. The general criteria for turnover ratios are discussed below.

1. Turnover ratios of 1 or greater generally apply to one of the following types of chemical enterprise: by-product operations, physical transformations, operations where raw materials represent a major portion of manufacturing cost, high labor requirements, or high-risk ventures.
2. Turnover ratios of less than 1 are found in larger-volume, stable market intermediates usually manufactured from very basic raw materials.

WORKING CAPITAL

Working capital may be defined as the funds necessary for the normal conduct of business. In general it will be found

Table 11. Working-capital Estimate

Raw-material inventory	$ ____
In-process inventory	____
Product inventory	____
Extended credit	____
Available cash	____
Working capital	$____

to be an amount equal to 10 to 15 per cent of the fixed-capital investment or 25 per cent of the annual product sales value. Specifically, working capital includes the value of raw-material stocks, in-process inventory, product inventory, extended credit, and funds available for the payment of wages and other expenses.[3,5]

Raw-material Inventory

The stocks of raw materials required for manufacturing are controlled by the rate of consumption, value, availability, source, and storage requirements. For estimating purposes a 1-month supply at purchased value may be used.

In-process Inventory

In chemical processing, the in-process inventory value depends upon the over-all length of the processing cycle. It may be estimated as one-half of the total manufacturing expense occurring during a period equivalent to the total hold-up time required for processing.

Product Inventory

The amount of product inventory which must be maintained varies considerably with the product. Some products are manufactured at a constant rate and are sold on a seasonal basis; others may be turned out campaignwise; many commodities may be perishable or unstable or may require special storage facilities. In absence of specific data, product inventory may be assumed to be equal to 1 month's production valued at manufacturing cost.

Extended Credit

Sufficient capital must be available to cover outstanding accounts for payment of merchandise delivered to customers. Extended credit may be estimated as 1 month's production at the sales value or at twice the manufacturing cost.

Available Cash

Funds are necessary for payment of wages and for services and materials. Available cash may be approximated as 1 month's manufacturing expense.

Equation for Working Capital

The following expression may be employed for approximating working capital:

$$I_w = r_m(m + 4M + 0.5MQ)$$

where I_w = working capital
r_m = monthly production rate
m = raw-material cost per unit of production
Q = production cycle, months
M = manufacturing cost per unit of production

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2. PHYSICAL-PLANT COST: EQUIPMENT

To the estimator the most important component of physical plant is the purchased cost of process equipment. This item forms the prime basis for determining capital costs, as indicated by the previous discussion of the six methods for fixed-capital estimation. In this chapter data for calculating the equipment cost are presented.

Six-tenths Factor

While the subsequently presented equipment-cost graphs represent a wide variety of process equipment, the estimator sometimes is faced with the problem of determining the cost of a piece of equipment at a capacity for which he has no cost data immediately available. To overcome this problem use may be made of what is commonly known as the six-tenths-factor rule, which states that if the cost of a given piece of equipment is known at one capacity, the cost of a similar unit x times as large may be approximated as $x^{0.6}$ times the price of the initial piece of equipment.[34–37]

$$E_b = E_a \left(\frac{c_b}{c_a} \right)^{0.6}$$

where c_a = capacity of equipment a
c_b = capacity of equipment b
E_a = purchased cost of equipment a
E_b = purchased cost of equipment b

The validity of this rule has been established. However, discretion should be employed in its use beyond a tenfold range of capacity. If the estimator has the cost of but one size of equipment, he must obviously use the 0.6 exponential value. However, with the prices of two or more different sizes of a unit it is possible to establish a more exact value for the particular exponent from the slope resulting from the logarithmic plot of cost versus capacity.

Indices

One of the prime difficulties facing the estimator is the fact that cost data once collected soon become obsolete because of ever-changing economic conditions. One cannot possibly obtain new quotations on every piece of equipment except on final approved design estimates. Thus a means must be available which will allow such cost data to be brought up to date. The answer lies in the use of indices, which are simply numbers for each year indicating the cost relative to a base year. To approximate current costs, the estimator has simply to multiply the old equipment cost of the unit by the ratio of the current index value to the index applicable to the year during which the old price was obtained.[7, 13, 20, 31, 32]

$$E_x = E_y \frac{\mathcal{N}_x}{\mathcal{N}_y}$$

where $\mathcal{N}_y$ = index value for year y
$\mathcal{N}_x$ = index value for year x
E_y = purchased-equipment cost for year y
E_x = purchased-equipment cost for year x

There has always been a great deal of criticism of indices, but they still represent the only means of achieving estimates, particularly of a preliminary nature, within a reasonable

length of time and without undue effort. However, too great a span of time should not be allowed to elapse in the correction of equipment prices, since technological advances may have had a decided effect upon the ultimate cost. Used judiciously within their realm of accuracy, indices are primary tools for the estimator. There are numerous indices in existence, differing slightly in their relative values because of variation in their component costs and base years. Table 12 shows the Marshall and Stevens all-industry and process-industry indices, the Nelson refinery index, and the *Engineering News-Record* construction index. The base year for which the index value is 100 is indicated for each. Current values of the Marshall and Stevens indices are published in *Chemical Engineering;* the Nelson index is listed in the *Oil and Gas Journal;* and the *Engineering News-Record* index is found in the magazine of the same name.

Indices reflect the change in cost over a period of time. Since total costs are composed of material and labor costs, indices will vary from one another according to the proportion and type of labor employed.

The *Engineering News-Record* construction index reflects the change in wage rates and in material-price trends for industrial construction. It is composed of a hypothetical block of construction of 2,500 lb of structural steel, 1,088 fbm of lumber, 6 bbl of cement, and 200 man-hours of common labor. The value of 100 applies to the base year, 1913.

The Marshall and Stevens all-industry index is simply the arithmetic average of the 47 different types of industrial indices reported by the firm. The Marshall and Stevens process-industry index is a weighted average of eight of these: cement, 2 per cent; chemicals, 48 per cent; clay products, 2 per cent; glass, 3 per cent; paints, 5 per cent; paper, 10 per cent; petroleum, 22 per cent; and rubber, 8 per cent. Comparative

equipment costs, developed to cover a composite of the whole plant, such as costs of various types of machinery, installation, and fixtures, are combined in proper proportion to the average occurrence in each plant, and they are computed for each one of the industries that are here represented. The base

Table 12. Selected Indices, 1943 to 1954

Year	Marshall and Stevens all-industry (1926 = 100)	Marshall and Stevens process-industry (1926 = 100)	Nelson refinery (1946 = 100)	*Eng. News-Record* construction (1913 = 100)
1943	101	101	87	290
1944	102	103	88	299
1945	103	104	90	308
1946	123	123	100	346
1947	151	149	117	413
1948	163	162	133	461
1949	161	161	140	477
1950	168	167	146	509
1951	180	178	157	542
1952	181	179	164	568
1953	183	181	174	599
1954	185	184	179	625

year, 1926, for the Marshall and Stevens indices has a value of 100.

The Nelson refinery index is designed specifically to reflect refinery construction. Material and labor components of refinery costs have been established as 40 and 60 per cent, respectively. Of the material portion, 60 per cent represents

iron and steel, and building materials and miscellaneous equipment are each represented by 20 per cent. Labor is seen to be divided evenly between common and skilled labor. The base year, to which the value of 100 is assigned, is 1946.

Purchased-equipment Cost

Once the rate of production has been ascertained and a rough flow sheet drawn, a list of the processing equipment may be compiled noting the size and material of construction. Figures 1 to 52 may in this case then be employed to determine the purchased cost of all items on the process-equipment list.

These graphs show the variation for 1954 of equipment costs, including normal auxiliaries and drives, as functions of capacity or size. The relationships are plotted on logarithmic paper in line with the six-tenths-factor correlation. It should be noted that the cost of any given piece of equipment is in reality controlled by numerous variables. For simplification these graphs are designed to show the trend in costs when all but one or perhaps two of the variables have been eliminated. It is recognized that a certain degree of precision is lost as far as any one piece of machinery is concerned. However, in view of some of the approximations which must be applied in the estimation of investment costs, the over-all accuracy of the total capital cost is not adversely affected to any serious extent. The subsequently presented equipment-cost graphs are arranged in alphabetical order and shown in Table 13. Inasmuch as it is impractical within the scope of this book to describe adequately each piece of equipment for which costs are shown, reference is made wherever possible to a page in "Chemical Engineers' Handbook" [28] where such information may be found.[1, 10, 14, 25]

Table 13. Content of Equipment-cost Graphs on Pages 21 to 72

Figure	*Graph*
1....	Air-conditioning units
2....	Blowers
3....	Centrifugal separators, batch
4....	Centrifugal separators, conveyor and high speed
5....	Compressors
6....	Condensers, barometric
7....	Conveyors, belt
8....	Conveyors, screw
9....	Conveyors, bucket
10....	Crystallizers, mechanical
11....	Crystallizers, vacuum
12....	Dowtherm units
13....	Dryers, drum and tray
14....	Dryers, rotary
15....	Dryers, spray
16....	Dust collectors, mechanical
17....	Dust collectors, electrical
18....	Ejectors, steam jet
19....	Evaporators, vertical
20....	Evaporators, horizontal and forced circulation
21....	Evaporators, jacketed
22....	Extractors
23....	Fans
24....	Filters, plate and frame
25....	Filters, sparkler
26....	Filters, leaf and rotary
27....	Flotation machines
28....	Gas producers
29....	Heat exchangers, shell and tube
30....	Heat exchangers, reboilers, jacketed pipe, and fin tube
31....	Incinerators
32....	Ion exchangers
33....	Mixers, propeller
34....	Mixers, sigma, pan, ribbon, and rotary
35....	Pumps, centrifugal
36....	Pumps, diaphragm, rotary, and reciprocating
37....	Pumps, vacuum
38....	Screens, vibrating
39....	Size reduction, crushers
40....	Size reduction, mills, cutters, and pulverizers
41....	Size reduction, ball mills
42....	Tanks, reactor
43....	Tanks, vacuum receiver
44....	Tanks, agitated
45....	Tanks, storage
46....	Tanks, storage
47....	Tanks, pressure
48....	Tanks, gas holder
49....	Thickeners, continuous
50....	Towers, bubble plate
51....	Towers, packed
52....	Water stills

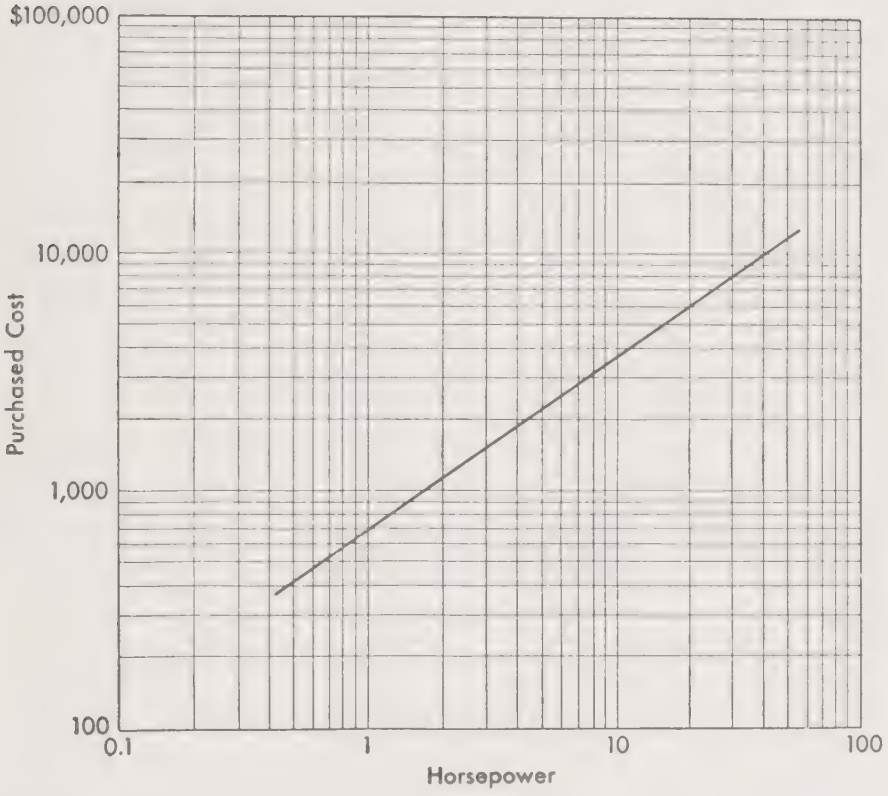


Fig. 1. Air-conditioning units. [Refs. 24, 28 (p. 778).]

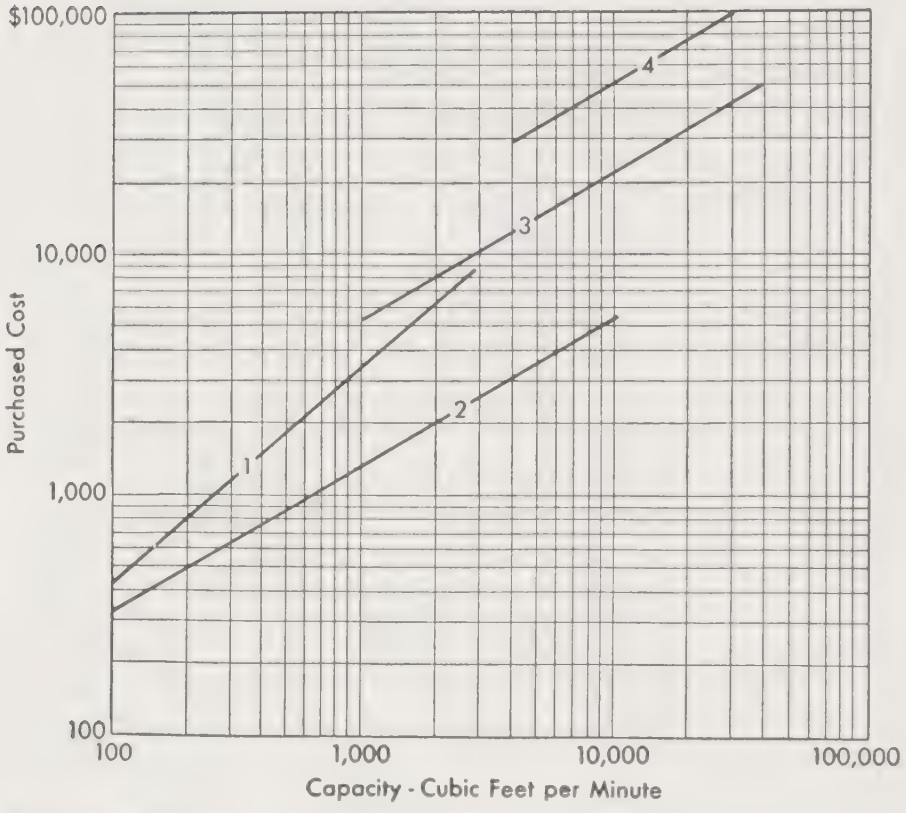


Fig. 2. Blowers. *Rotary:* (1) 10 to 15 psi. *Centrifugal turbo:* (2) 0.5 to 2 psi, (3) 7 to 10 psi, (4) 20 to 30 psi. [Refs. 2, 3, 5, 8, 27, 28 (pp. 1450, 1452), 34.]

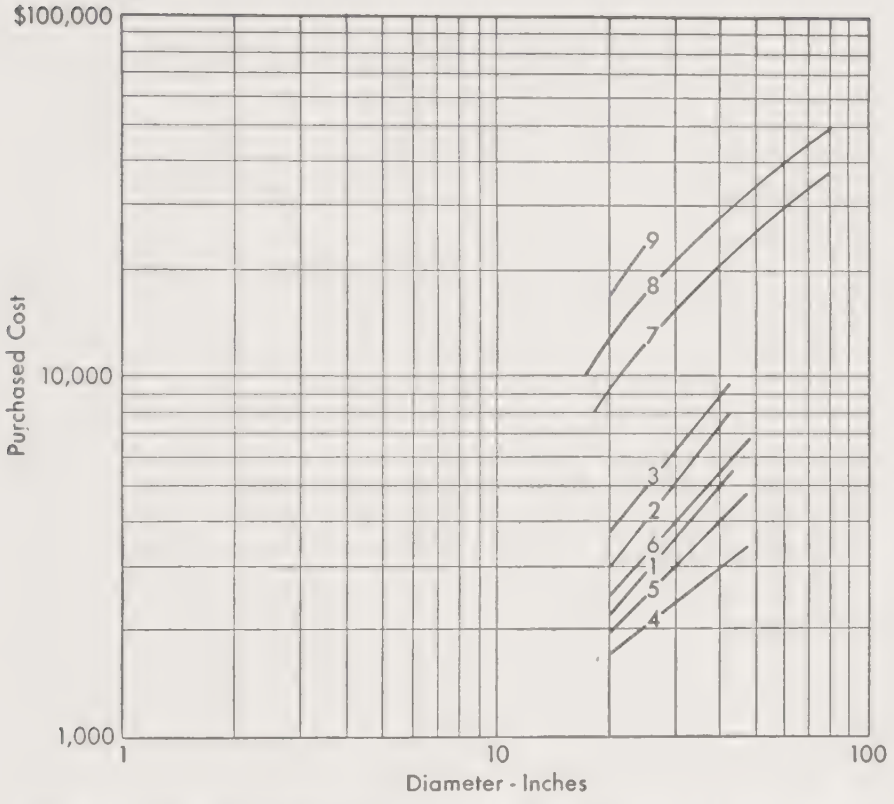


Fig. 3. Centrifugal separators. *Batch, top suspended:* (1) steel, (2) rubber-covered steel, (3) stainless steel. *Batch, bottom driven:* (4) steel, (5) rubber-covered steel, (6) stainless steel. *Batch, automatic:* (7) Baker-Perkins steel, (8) Baker-Perkins stainless steel, (9) Sharples Super D Hydrator stainless steel. [Refs. 5, 22, 27, 28 (p. 997), 30, 38.]

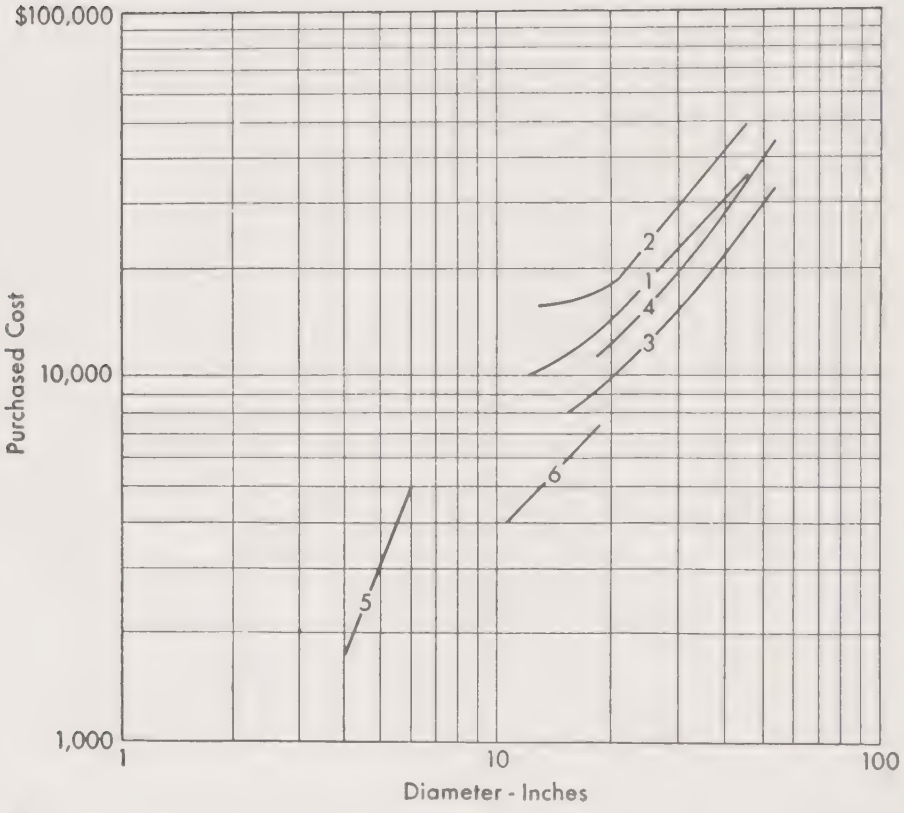


Fig. 4. Centrifugal separators. *Conveyor, reciprocating:* (1) steel, (2) stainless steel. *Conveyor, scroll:* (3) Bird steel, (4) Bird stainless steel. *High speed:* (5) tubular, (6) disk. [Refs. 5, 11, 27, 28 (pp. 998–1000), 30, 38.]

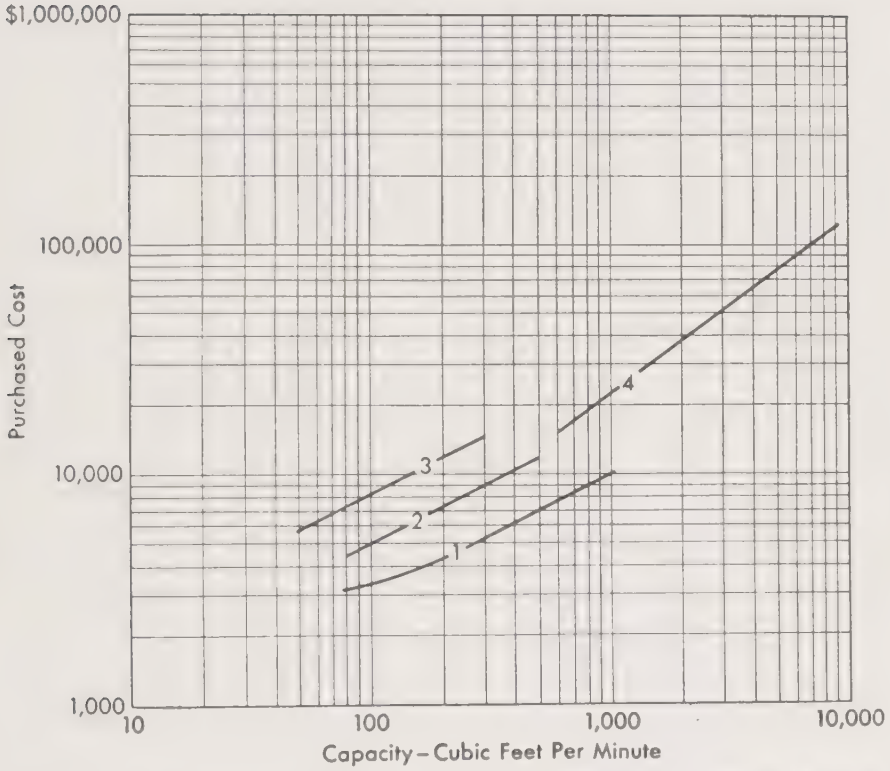


Fig. 5. Compressors. *Single, reciprocating:* (1) one stage (20 to 150 psi), (2) two stages (150 to 500 psi), (3) three stages (900 to 2,500 psi). *Duplex, reciprocating:* (4) two stages (80 to 125 psi). [Refs. 5, 18, 27, 28 (p. 1258).]

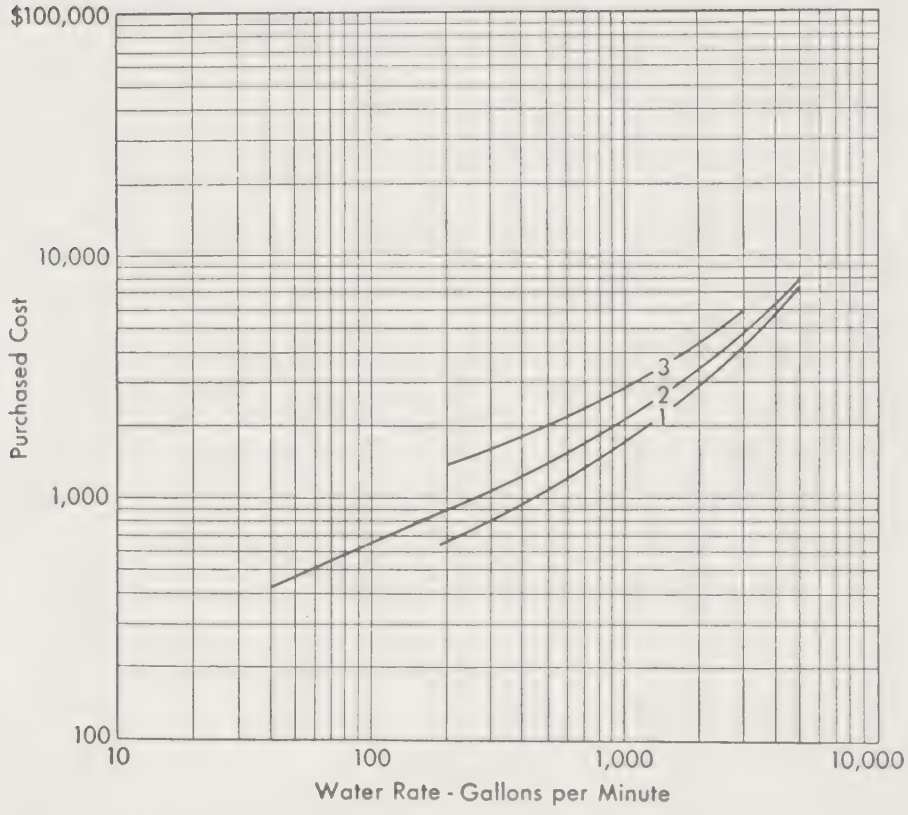


Fig. 6. Condensers. *Barometric:* (1) steel, (2) cast iron, (3) rubber-lined steel. [Refs. 21, 27, 28 (p. 520).]

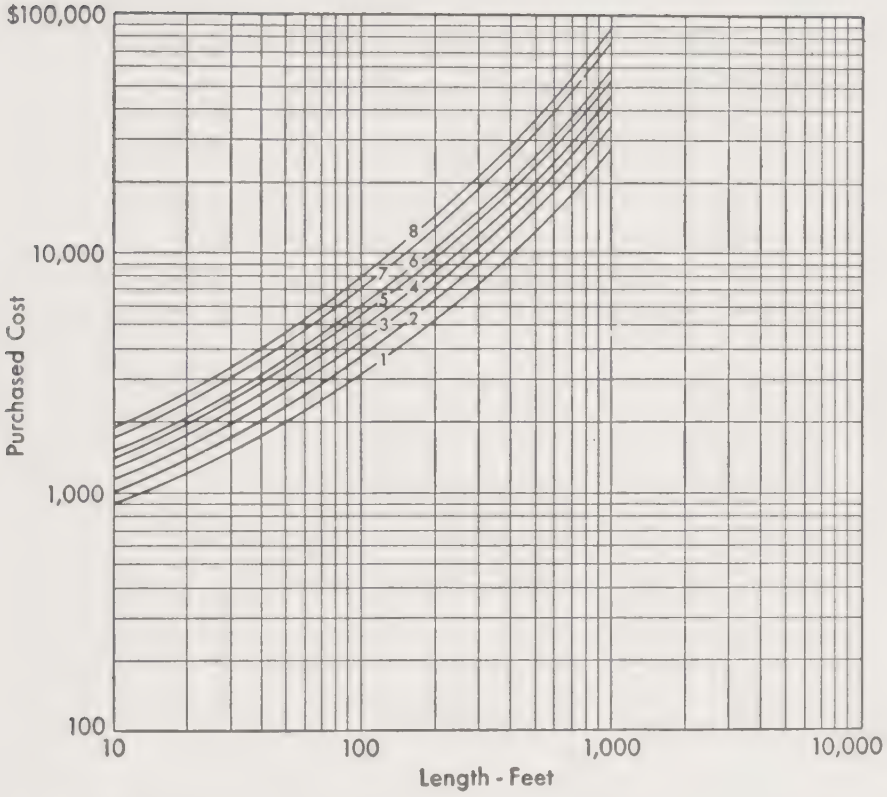


Fig. 7. Conveyors. *Belt, open:* (1) 18 in. belt width, (2) 24 in. belt width, (3) 30 in. belt width, (4) 36 in. belt width. *Belt, enclosed with walkways:* (5) 18 in. belt width, (6) 24 in. belt width, (7) 30 in. belt width, (8) 36 in. belt width. [Refs. 28 (p. 1354), 39.]

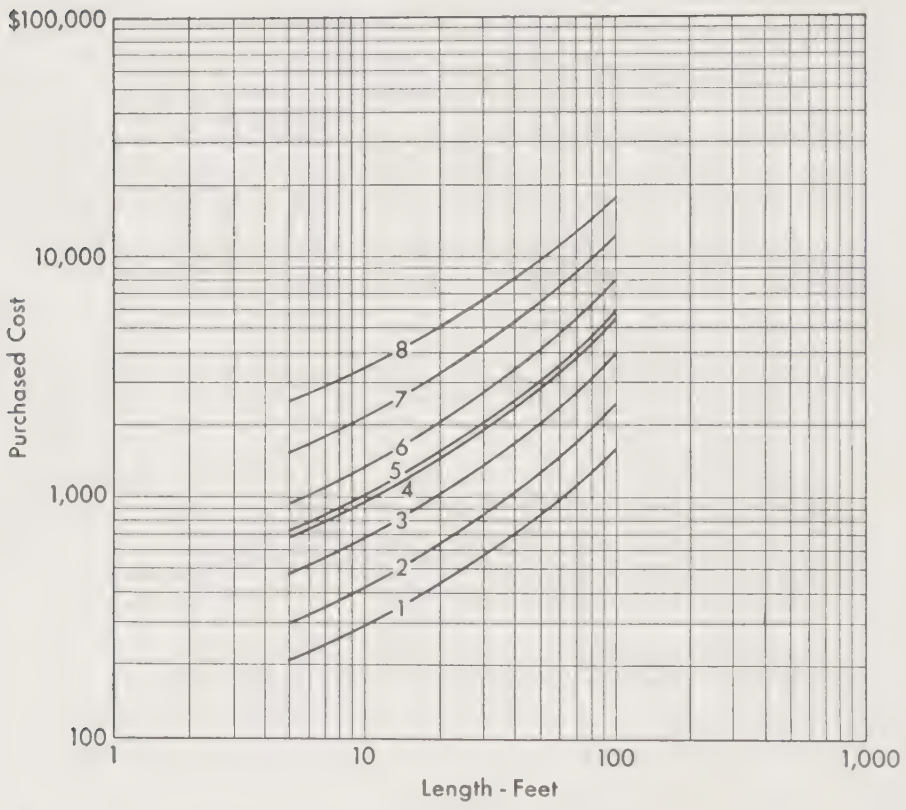


Fig. 8. Conveyors. *Screw, steel:* (1) 6 in. diameter, (2) 12 in. diameter, (3) 16 in. diameter, (4) 20 in. diameter. *Screw, stainless steel:* (5) 6 in. diameter, (6) 12 in. diameter, (7) 16 in. diameter, (8) 20 in. diameter. [Refs. 17, 28 (p. 1344), 39.]

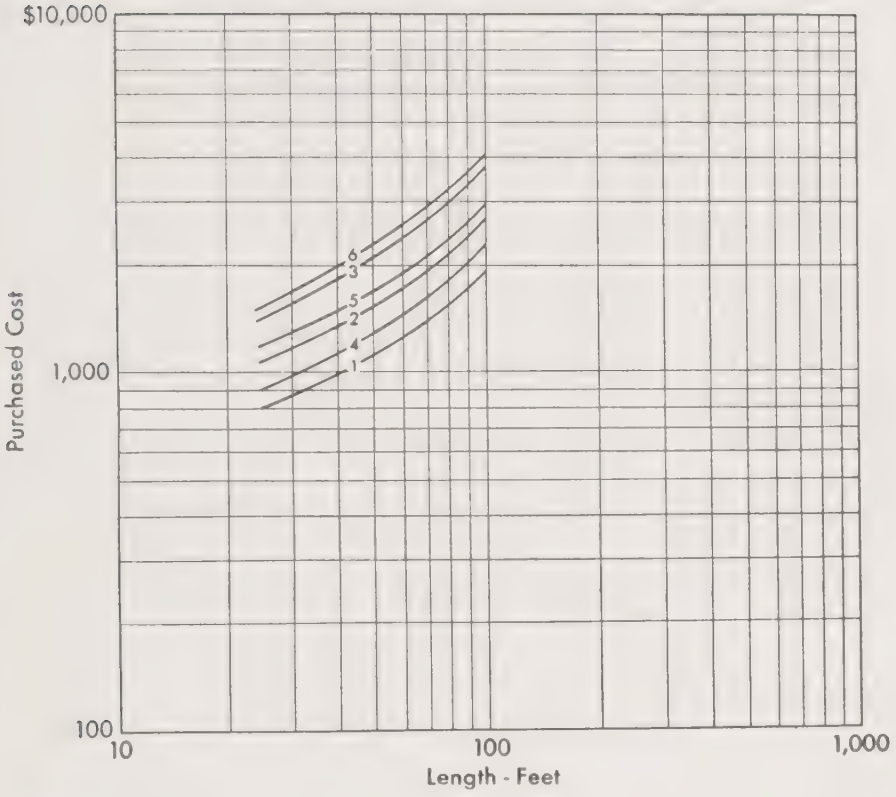


Fig. 9. Conveyors. *Spaced-bucket elevator:* (1) 6 by 4 by 4¼ in., 14 tons per hr (100 lb per cu ft), (2) 12 by 7 by 7¼ in., 84 tons per hr, (3) 16 by 8 by 8½ in., 150 tons per hr. *Continuous-bucket elevator:* (4) 8 by 5½ by 7¾ in., 35 tons per hr, (5) 14 by 7 by 11¾ in., 80 tons per hr, (6) 16 by 8 by 11¾ in., 115 tons per hr. [Refs. 28 (p. 1348), 39.]

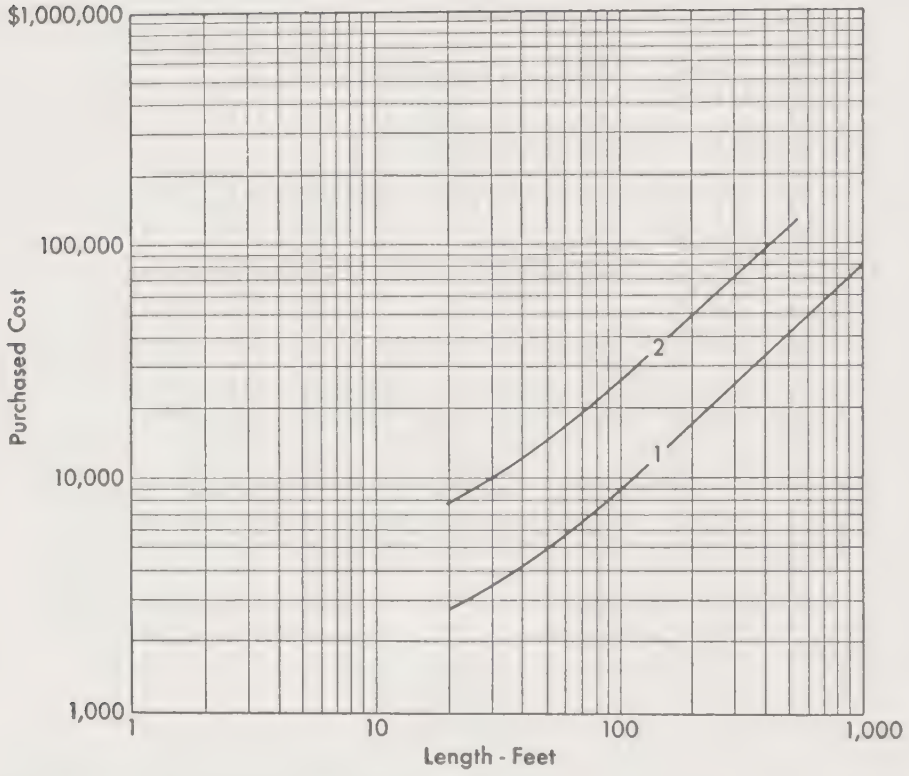


Fig. 10. Crystallizers. *Swenson-Walker mechanical:* (1) steel and cast iron, (2) stainless steel. [Refs. 2, 3, 27, 28 (p. 1063), 34, 38.]

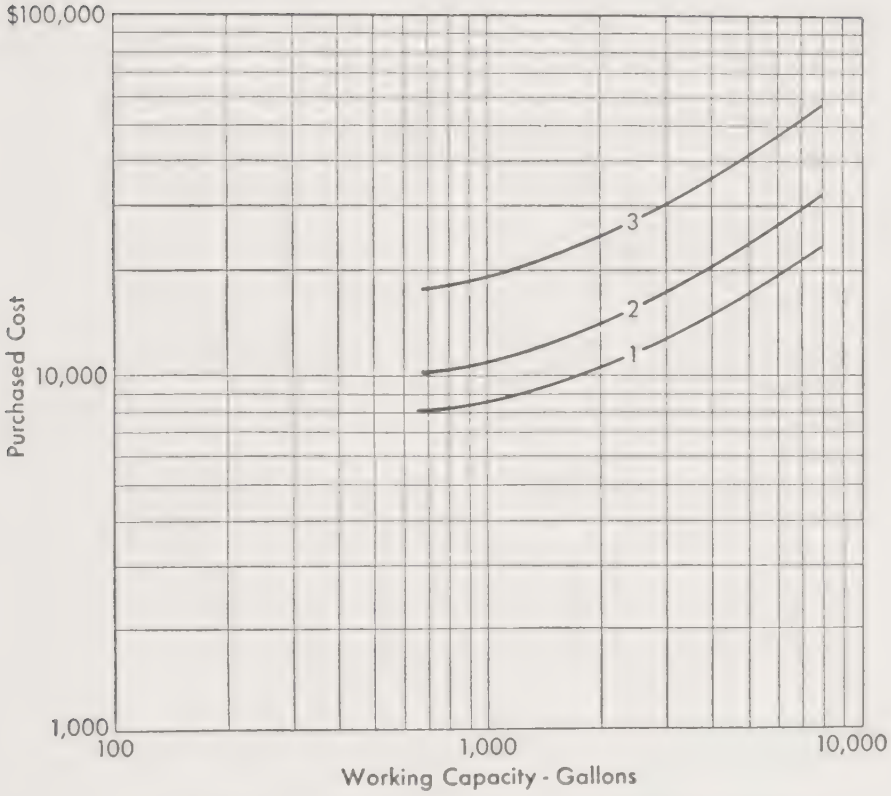


Fig. 11. Crystallizers. *Batch, vacuum:* (1) steel, (2) rubber-lined steel, (3) stainless steel. [Refs. 28 (p. 1065), 38.]

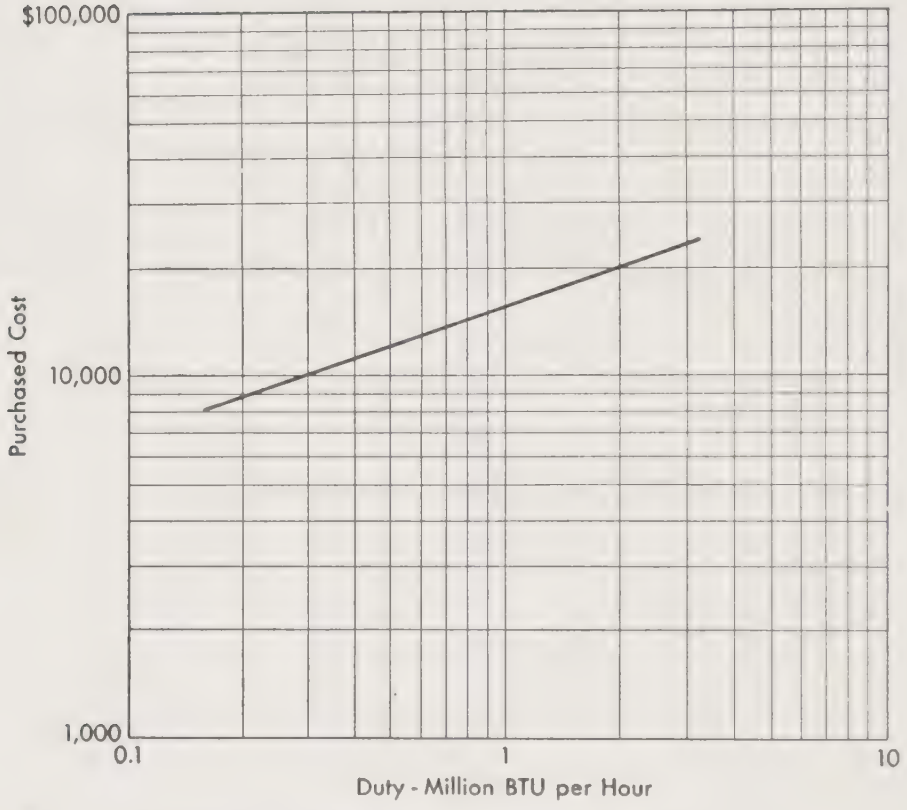


Fig. 12. Dowtherm units. [Refs. 5, 28 (pp. 1223, 1605).]

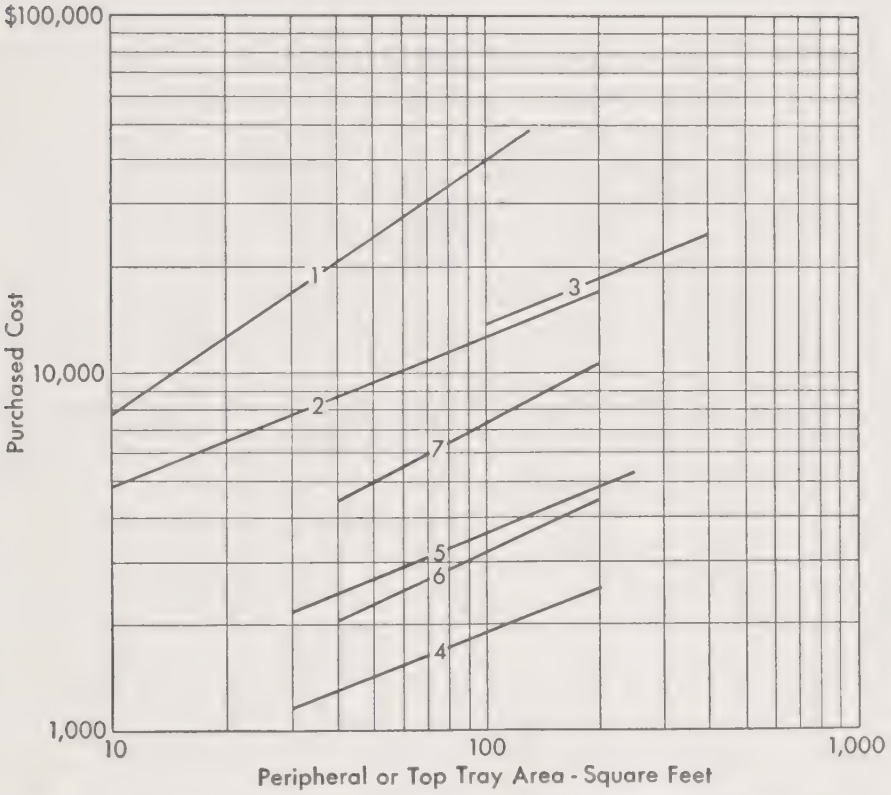


Fig. 13. Dryers. *Drum:* (1) vacuum, single, (2) atmospheric, single, (3) atmospheric, double. *Tray, atmospheric:* (4) steel, (5) stainless steel. *Tray, vacuum:* (6) steel, (7) stainless steel. [Refs. 2, 3, 5, 22, 27, 28 (pp. 815, 853, 863, 864), 34.]

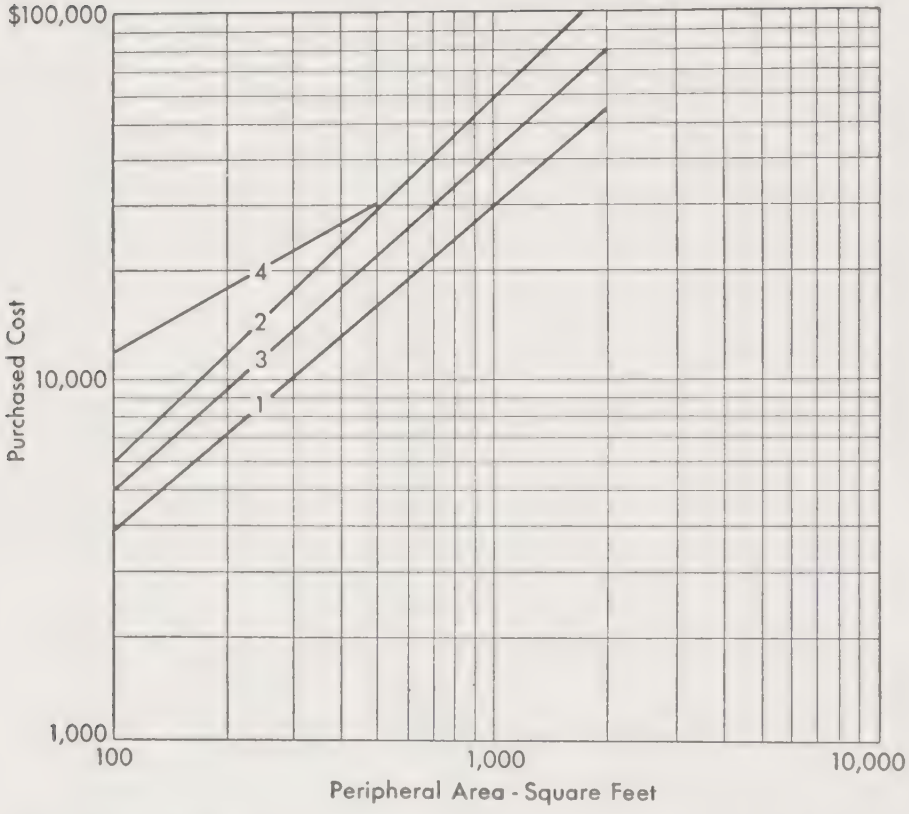


Fig. 14. Dryers. *Rotary:* (1) hot air, (2) flue gas, indirect, (3) flue gas, direct, (4) vacuum. [Refs. 2, 3, 5, 27, 28 (pp. 828, 858, 859), 34.]

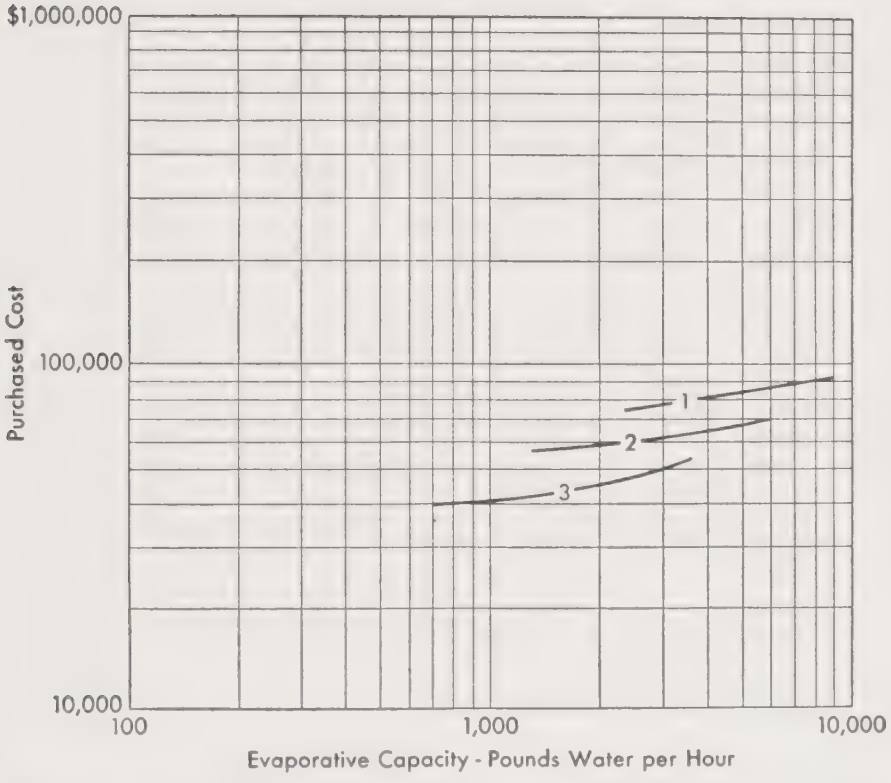


Fig. 15. Dryers. *Spray:* (1) 18 ft diameter, (2) 14 ft diameter, (3) 10 ft diameter. [Refs. 5, 12, 27, 28 (p. 838).]

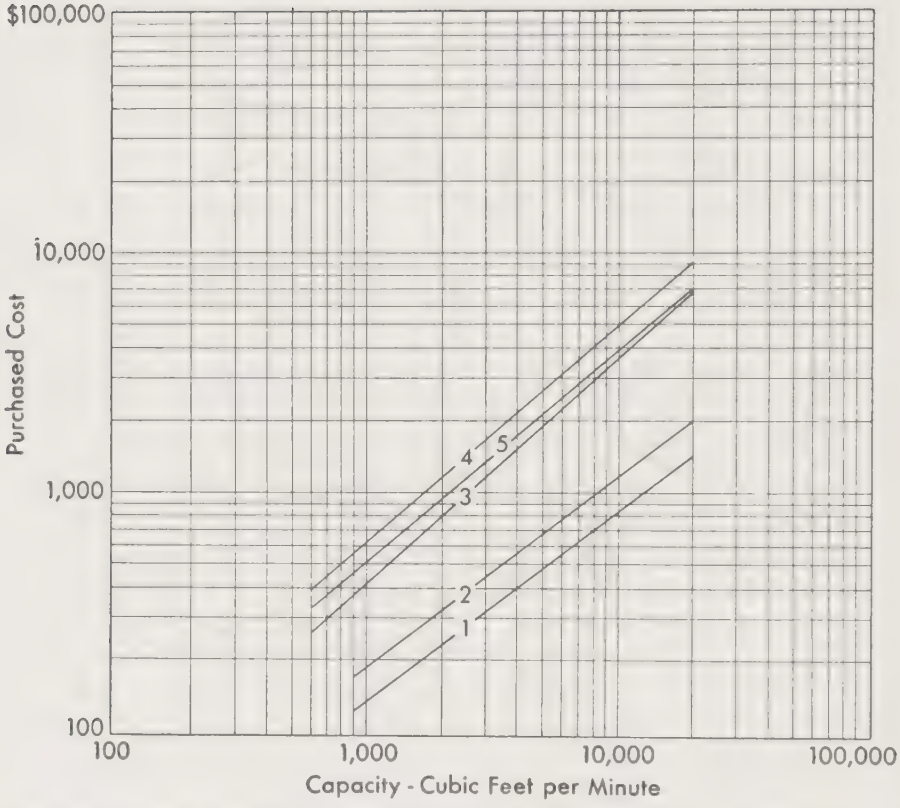


Fig. 16. Dust collectors. (1) Cyclones, (2) multiple cyclones, (3) washers, (4) automatic cloth filters, (5) centrifugal precipitators. [Refs. 5, 27, 28 (pp. 1023, 1028, 1034, 1045), 38.]

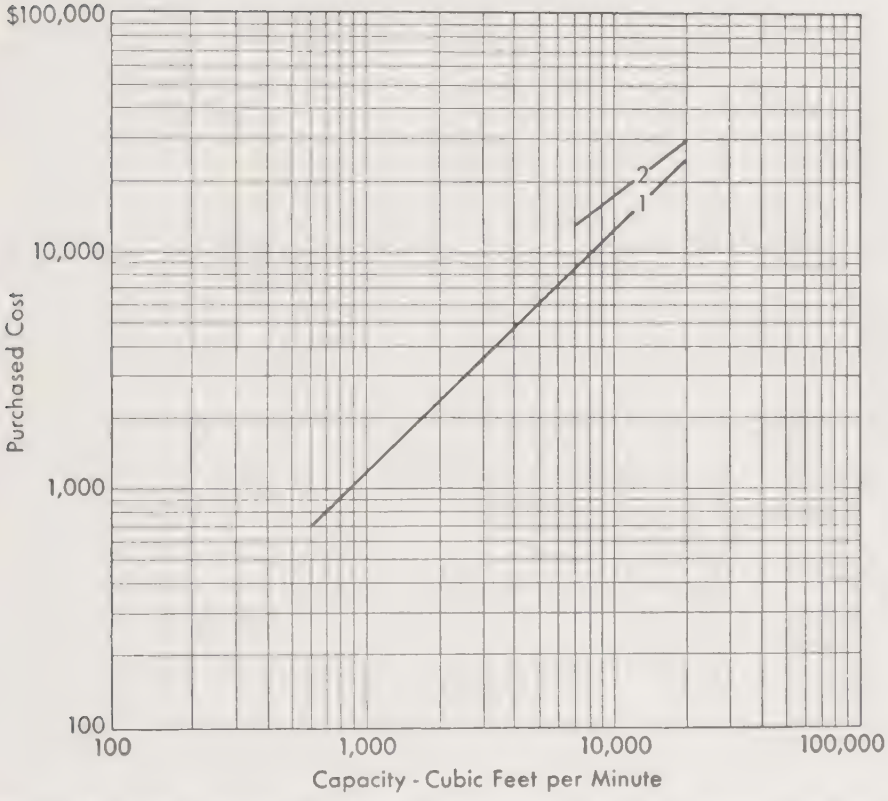


Fig. 17. Dust collectors. *Electric precipitators:* (1) low voltage, (2) high voltage. [Refs. 28 (p. 1039), 38.]

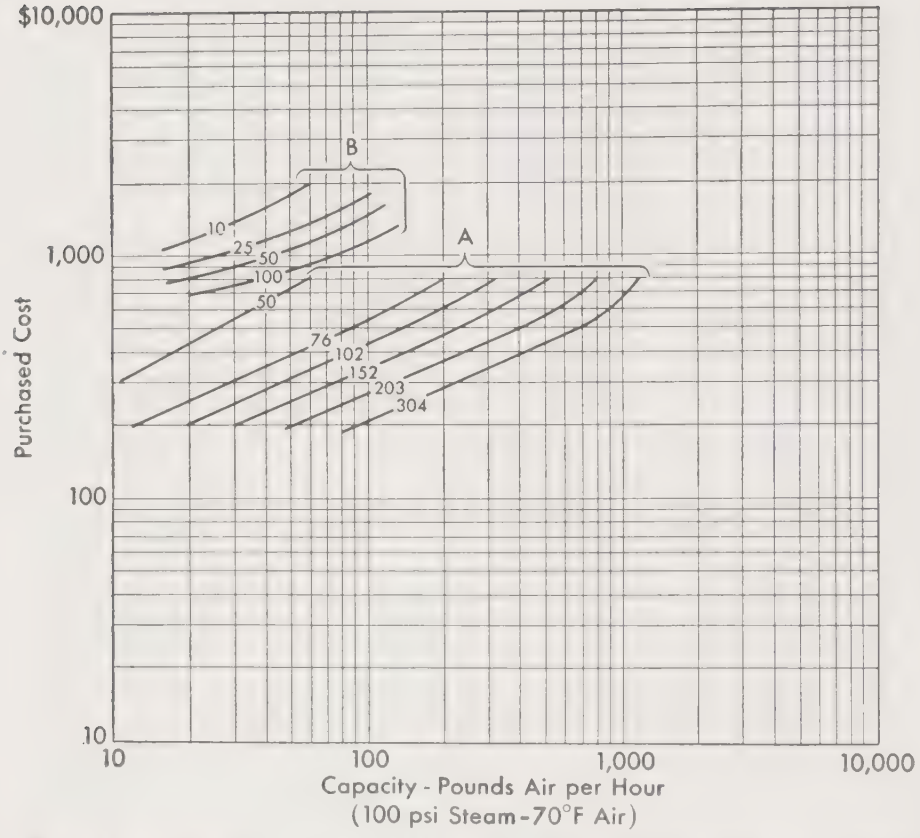


Fig. 18. Ejectors. *Steam jet:* (A) single stage, noncondensing, at various pressures in millimeters of mercury, (B) two stages, barometric type of intercondenser, at various pressures in millimeters of mercury. [Refs. 21, 27, 28 (p. 1453), 33, 38.]

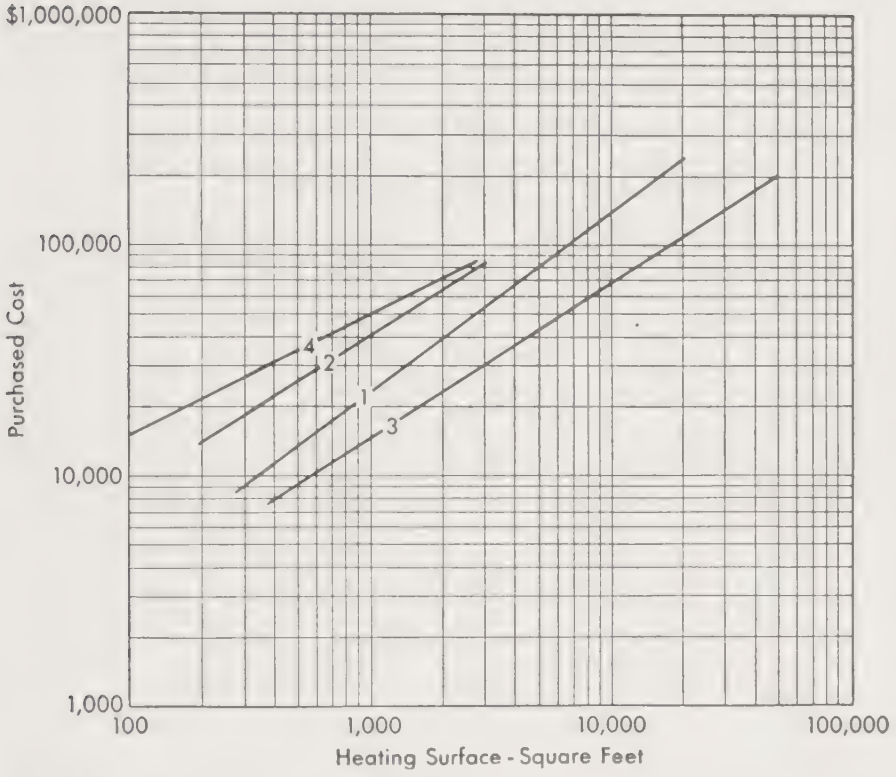


Fig. 19. Evaporators. *Long tube vertical:* (1) cast-iron body, copper tubes, (2) copper, (3) steel, (4) rubber-lined steel body, Karbate tubes. [Refs. 2, 3, 5, 27, 28 (p. 506), 34, 38.]

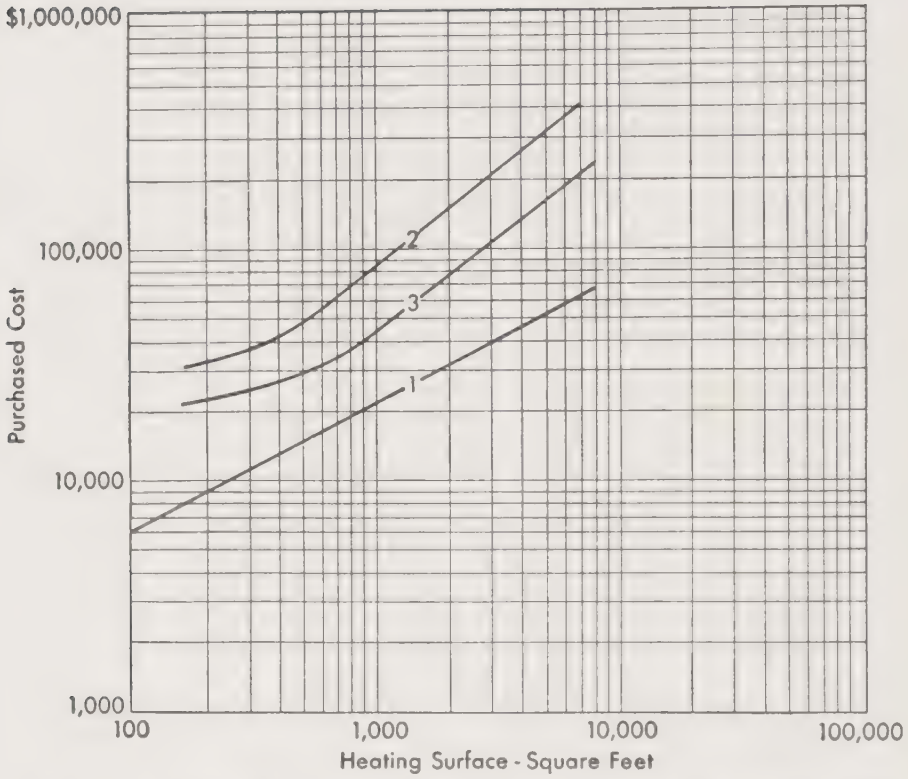


Fig. 20. Evaporators. *Horizontal tube:* (1) cast-iron body, copper tubes; steel. *Forced circulation:* (2) nickel, cast-iron body, nickel tubes, (3) cast-iron body, copper tubes. [Refs. 2, 3, 5, 27, 28 (p. 506), 34.]

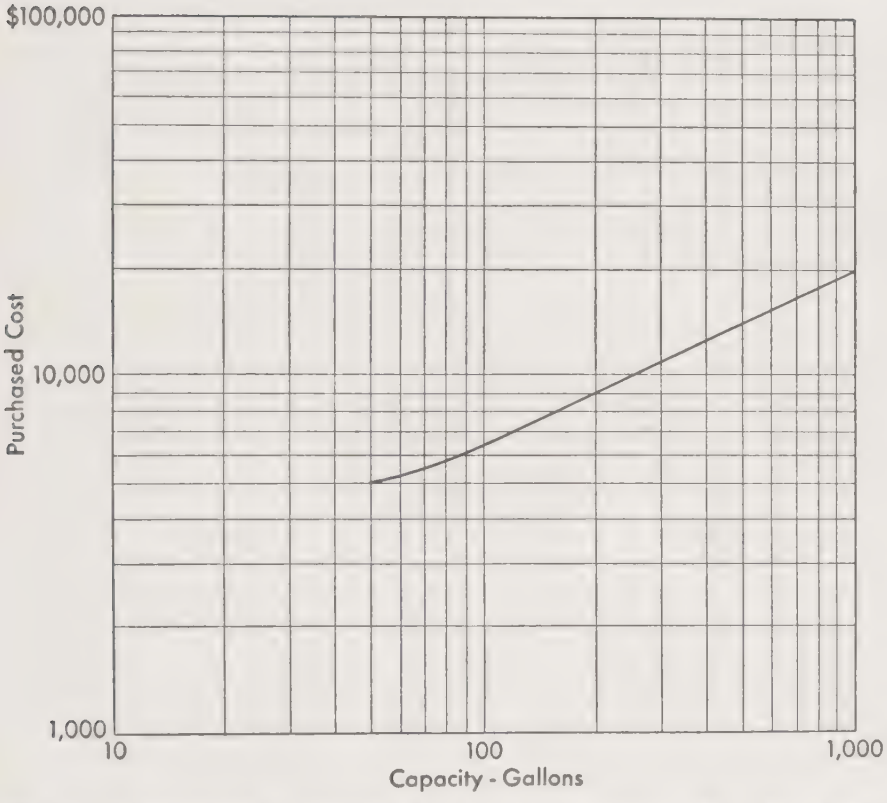


Fig. 21. Evaporators. Jacketed, glass-lined steel vessels. [Ref. 28 (p 505).]

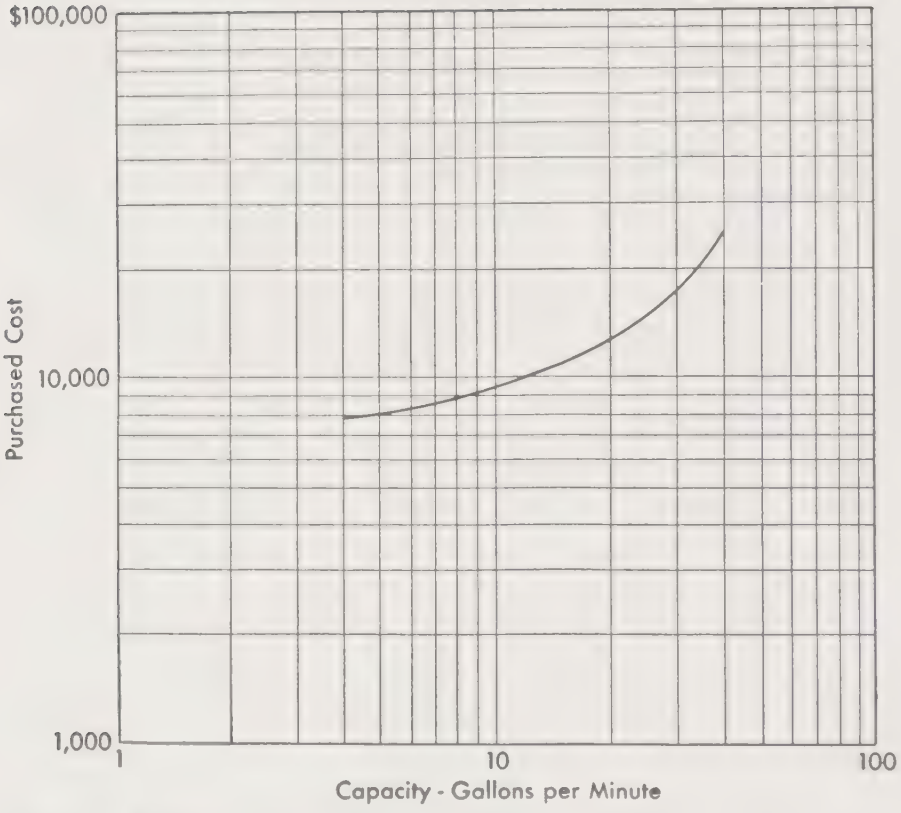


Fig. 22. Extractors. Continuous centrifugal. [Ref. 28 (p. 748).]

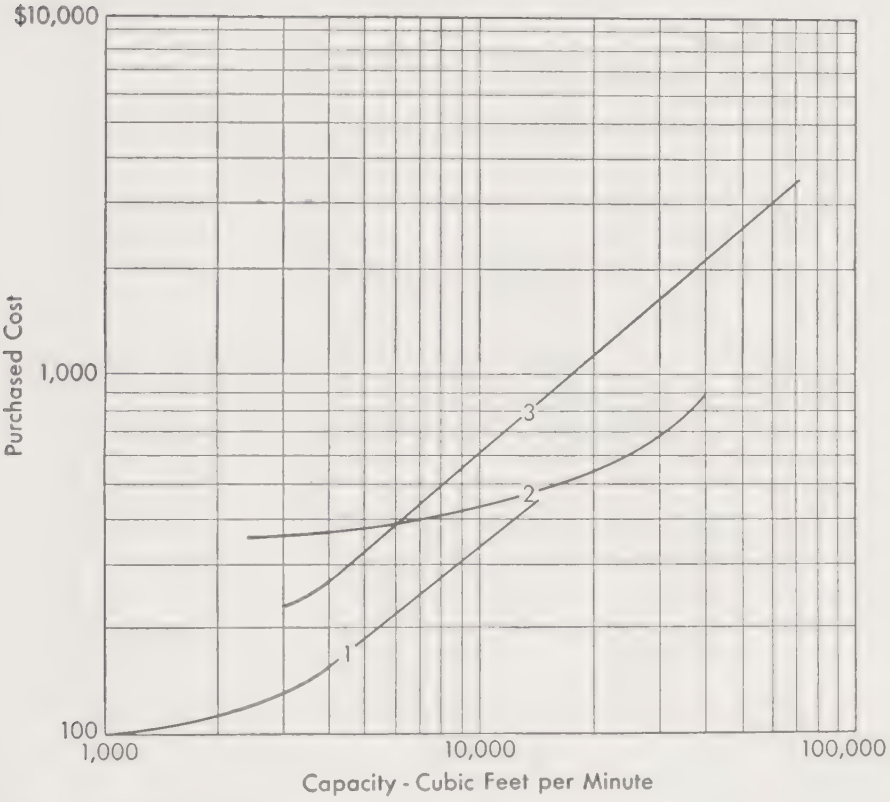


Fig. 23. Fans. (1) Propeller, (2) vaneaxial, (3) centrifugal. [Refs. 5, 8, 28 (pp. 1208, 1448), 38.]

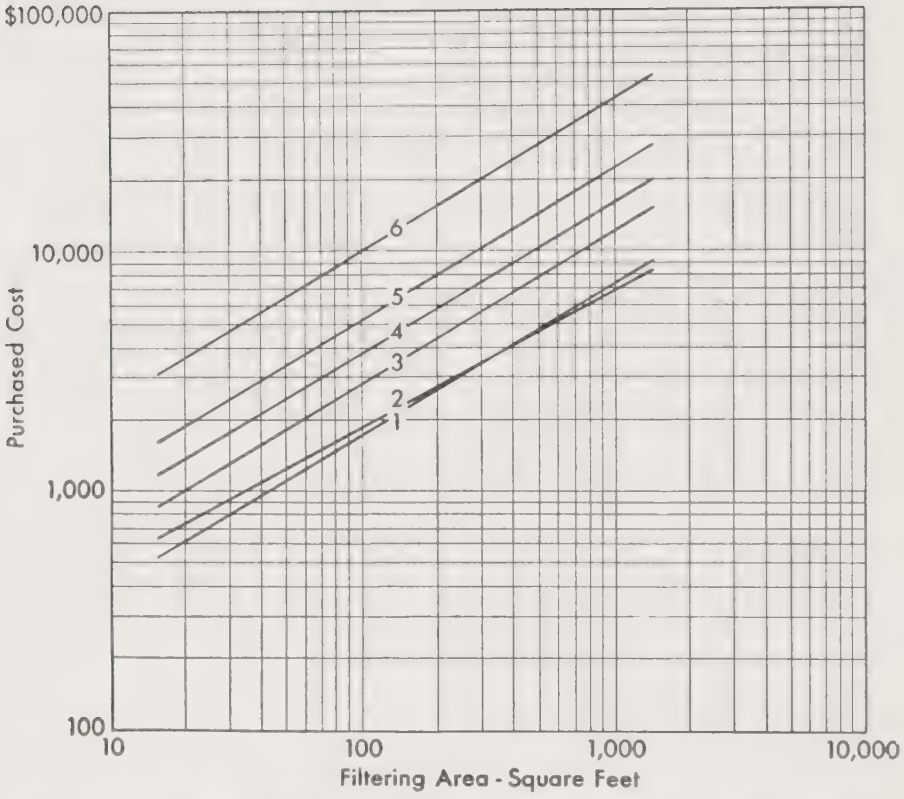


Fig. 24. Filters. *Plate and frame:* (1) cast iron, (2) yellow pine, (3) aluminum, (4) lead, (5) bronze, (6) stainless steel. [Refs. 2, 3, 5, 27, 28 (p. 970), 34, 38.]

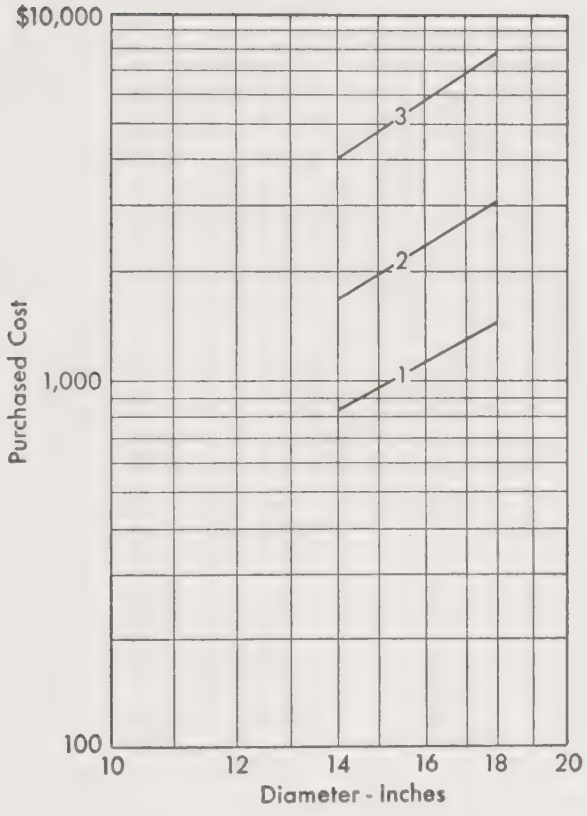


Fig. 25. Filters. *Sparkler:* (1) carbon steel, (2) stainless steel, (3) Hastelloy. [Refs. 22, 28 (p. 988).]

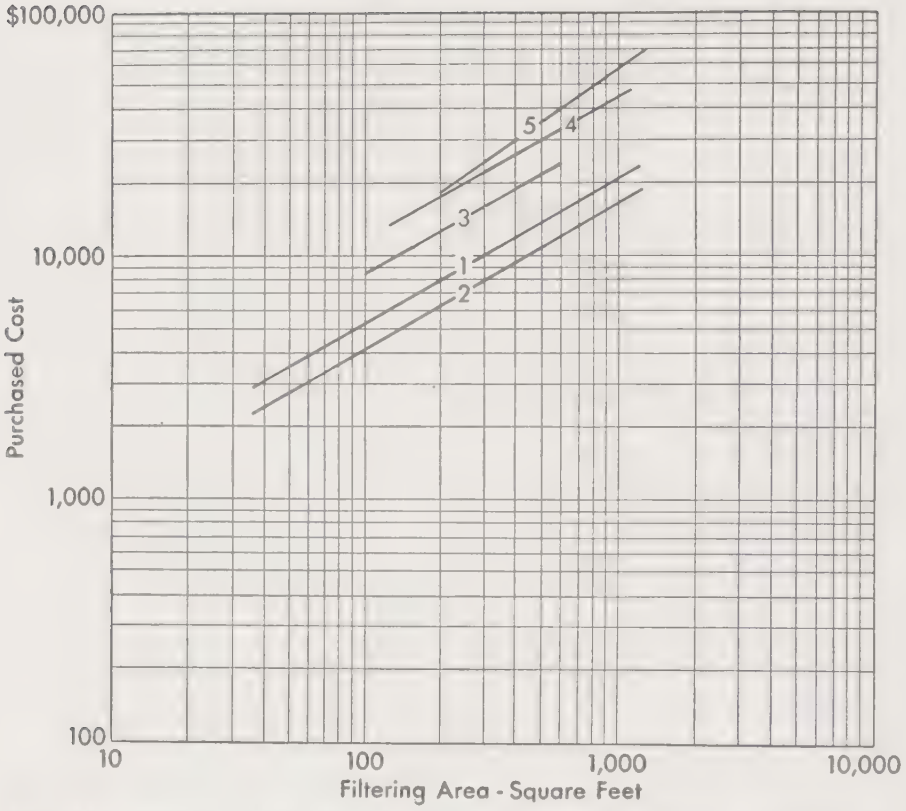


Fig. 26. Filters. *Leaf:* (1) 4 in. spacing, (2) 2 in. spacing. *Sewage:* (3). *Rotary: (4) drum,* (5) disk. [Refs. 2, 3, 5, 28 (pp. 970, 986), 34, 38.]

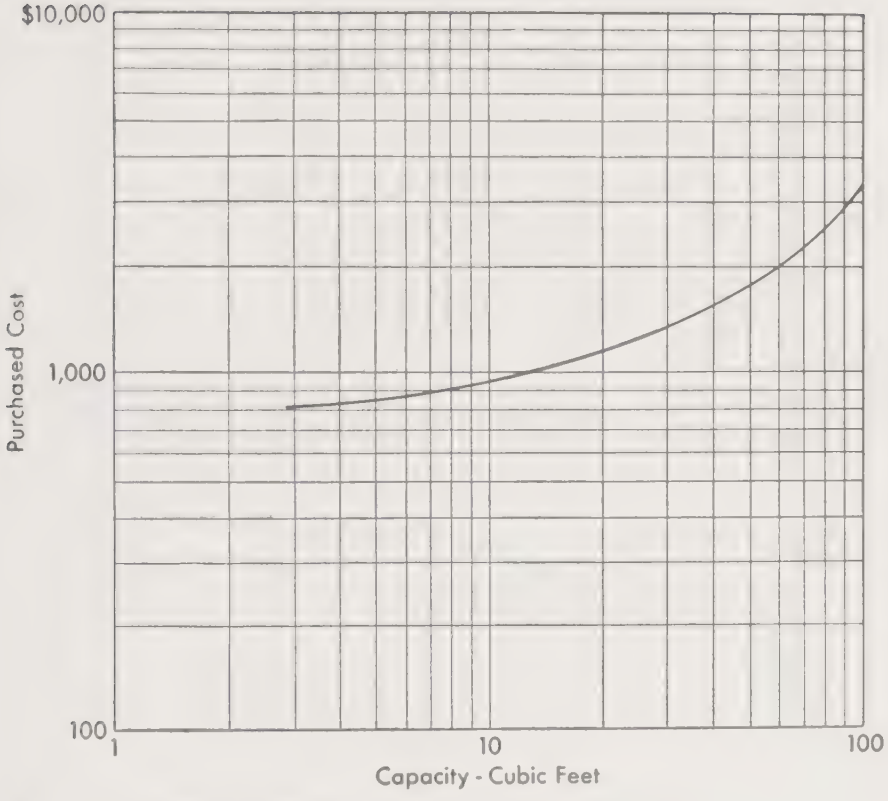


Fig. 27. Flotation machines. [Refs. 28 (p. 1089), 39.]

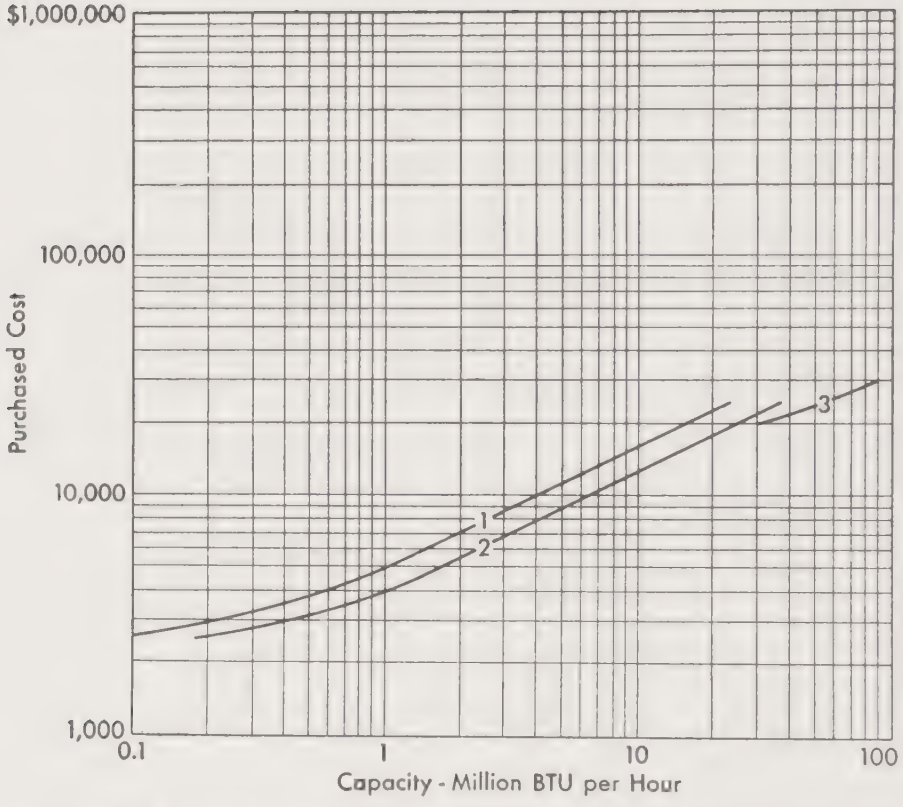


Fig. 28. Gas producers. (1) Coke, (2) anthracite, (3) bituminous. [Refs. 5, 27, 28 (p. 1617), 39.]

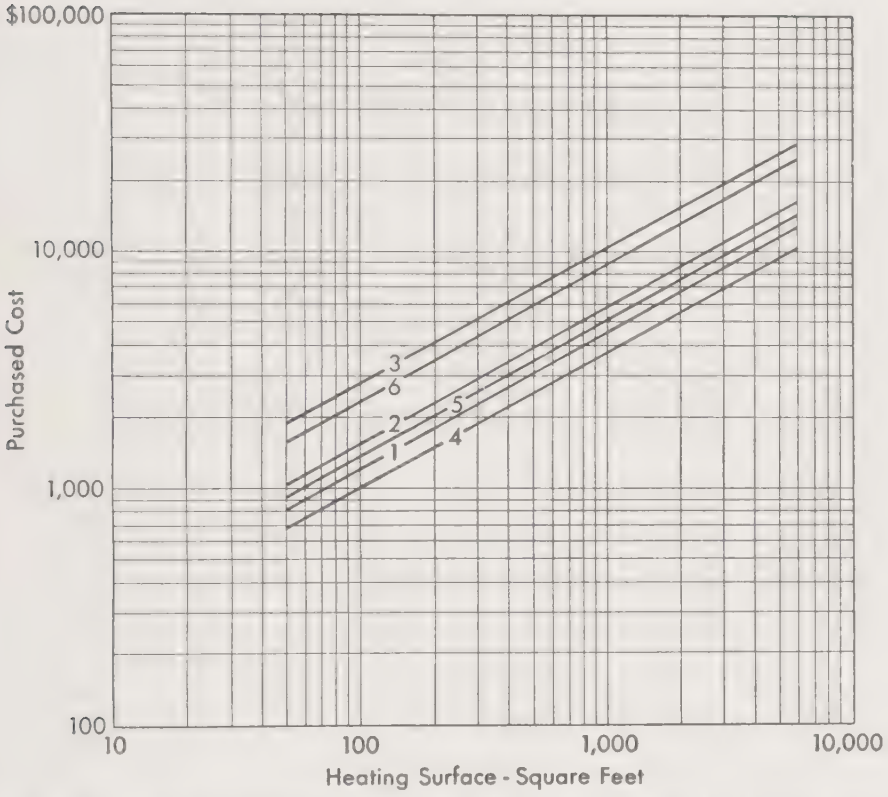


Fig. 29. Heat exchangers. *Shell and tube, floating head:* (1) steel shell, steel tubes, (2) steel shell, copper tubes, (3) steel shell, stainless-steel tubes. *Shell and tube, fixed-tube sheet and U tube:* (4) steel shell, steel tubes, (5) steel shell, copper tubes, (6) steel shell, stainless-steel tubes. [Refs. 2, 3, 5, 18, 27, 28 (pp. 482, 1688), 29, 34, 38, 39.]

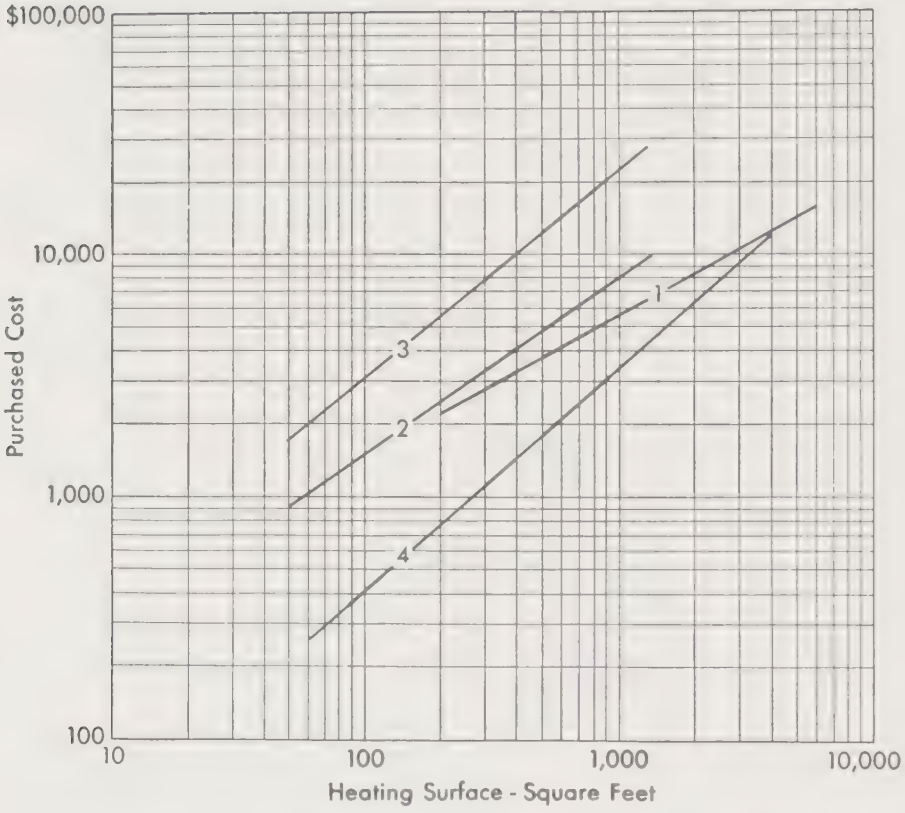


Fig. 30. Heat exchangers. *Steel reboilers:* (1). *Jacketed pipe:* (2) steel, (3) glass and steel. *Steel fin tube:* (4). [Refs. 2, 3, 5, 18, 27, 28 (pp. 473, 482, 1688), 29, 34, 38, 39.]

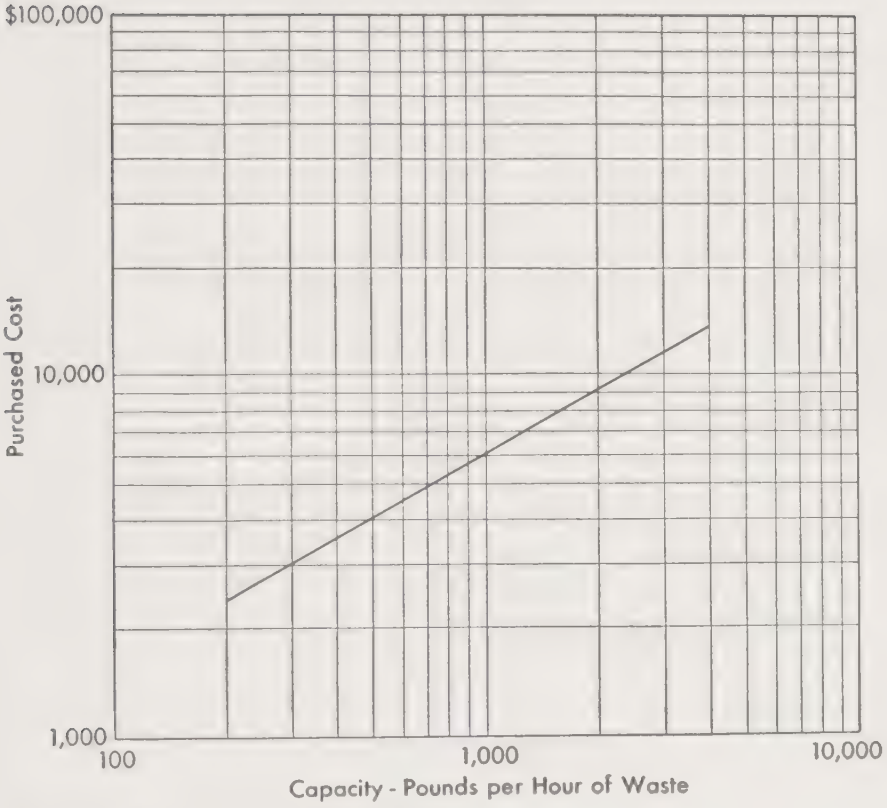


Fig. 31. Incinerators. [Ref. 39.]

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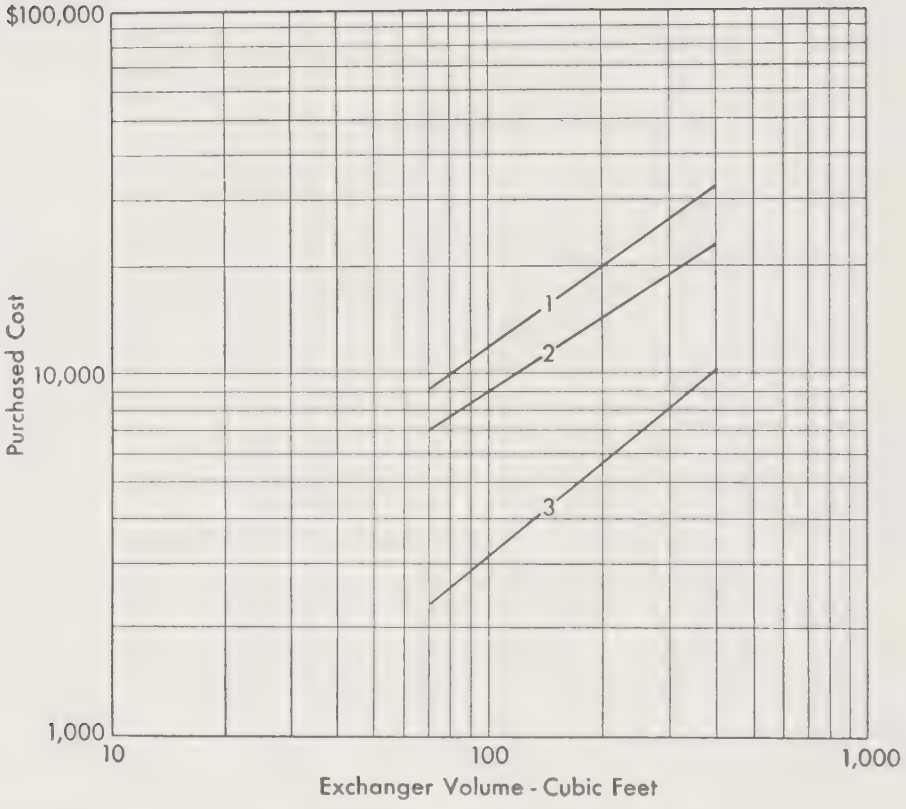


Fig. 32. Ion exchangers. (1) Anion, (2) hydrogen-cycle cation, (3) sodium-cycle cation. [Refs. 26, 28 (p. 915).]

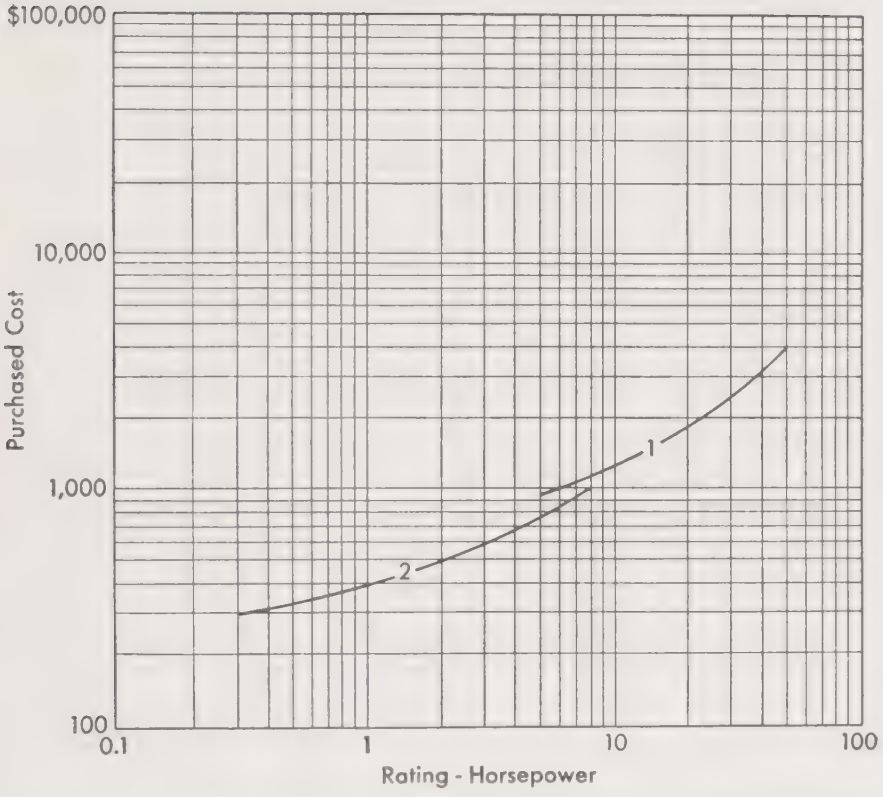


Fig. 33. Mixers. (1) Fixed propeller, (2) portable propeller. [Refs. 23, 28 (pp. 1208, 1209), 39.]

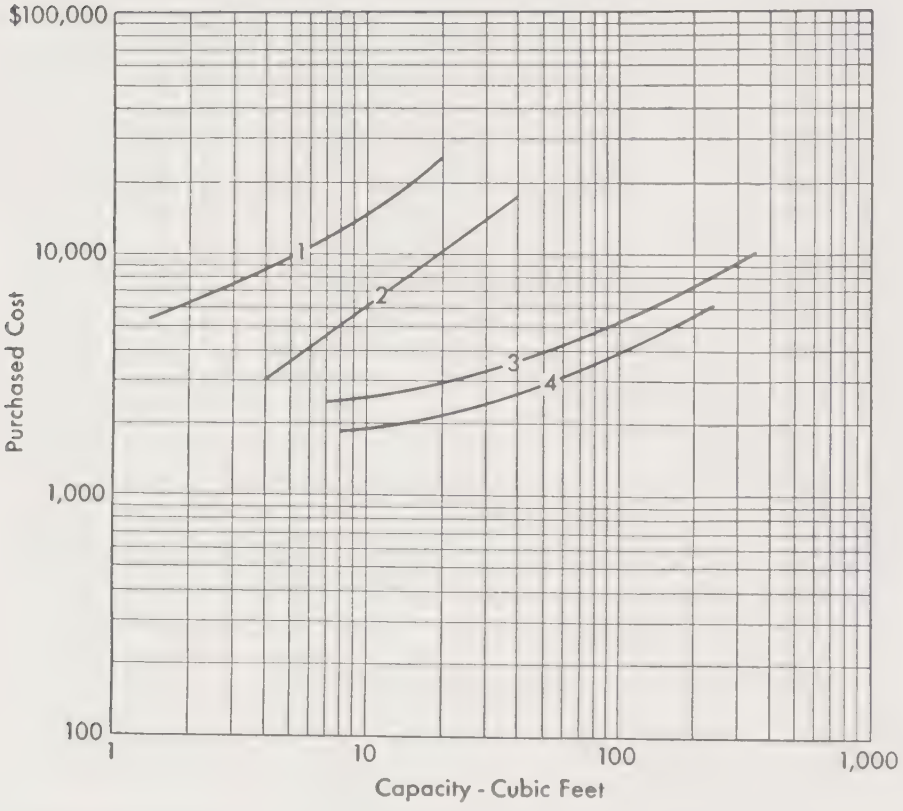


Fig. 34. Mixers. (1) Sigma mixer, (2) pan mixer, (3) ribbon blender, (4) rotary blender. [Refs. 23, 28 (pp. 1207, 1210, 1212, 1214).]

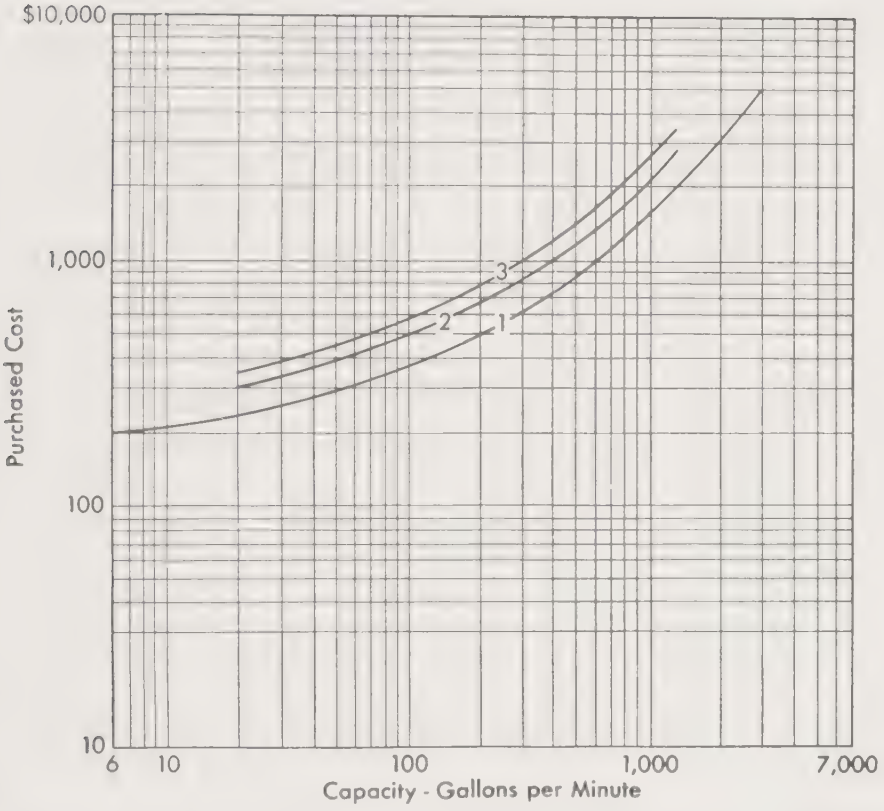


Fig. 35. Pumps. *Centrifugal:* (1) iron, (2) bronze, (3) stainless steel. [Refs. 2, 3, 5, 18, 27, 28 (p. 1417), 34.]

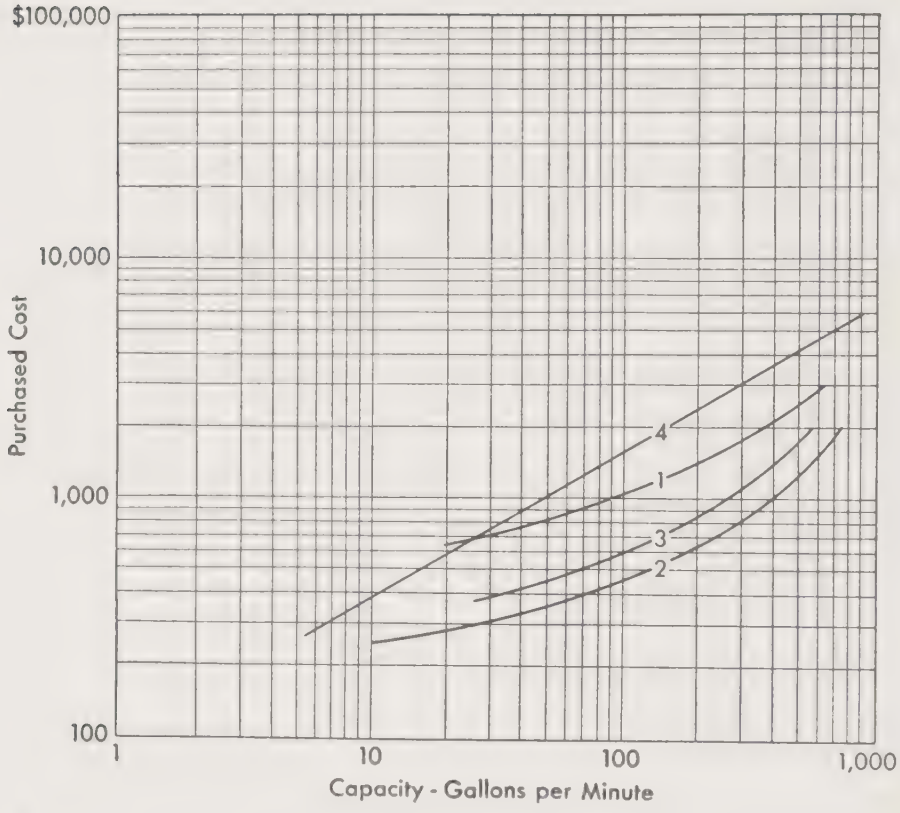


Fig. 36. Pumps. *Diaphragm:* (1). *Rotary:* (2) iron, (3) bronze. *Reciprocating:* (4). [Refs. 2, 3, 5, 27, 28 (pp. 990, 1436, 1437), 34, 39.]

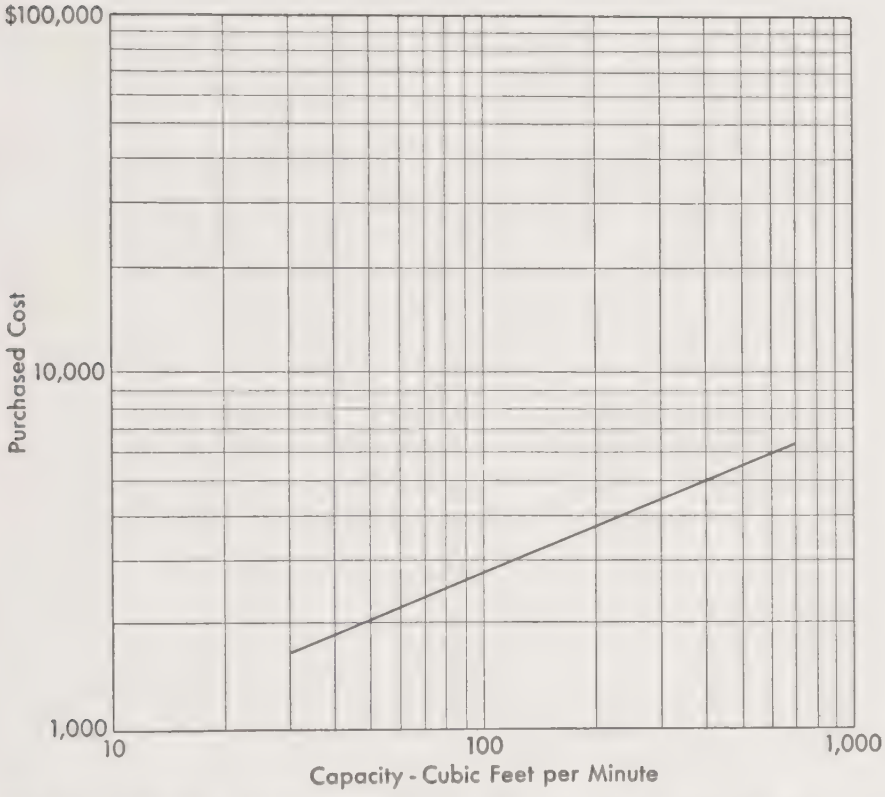


Fig. 37. Pumps. Mechanical vacuum. [Refs. 27, 28 (p. 990), 38, 39.]

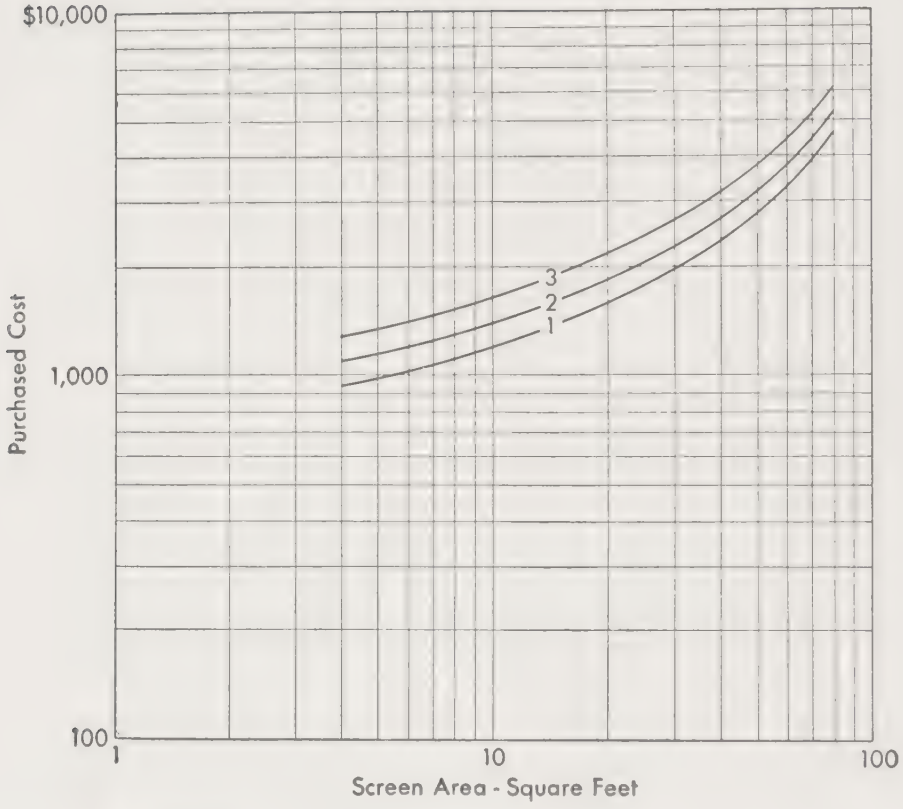


Fig. 38. Screens. *Vibrating:* (1) single deck, (2) double deck, (3) triple deck. [Refs. 4, 28 (p. 956).]

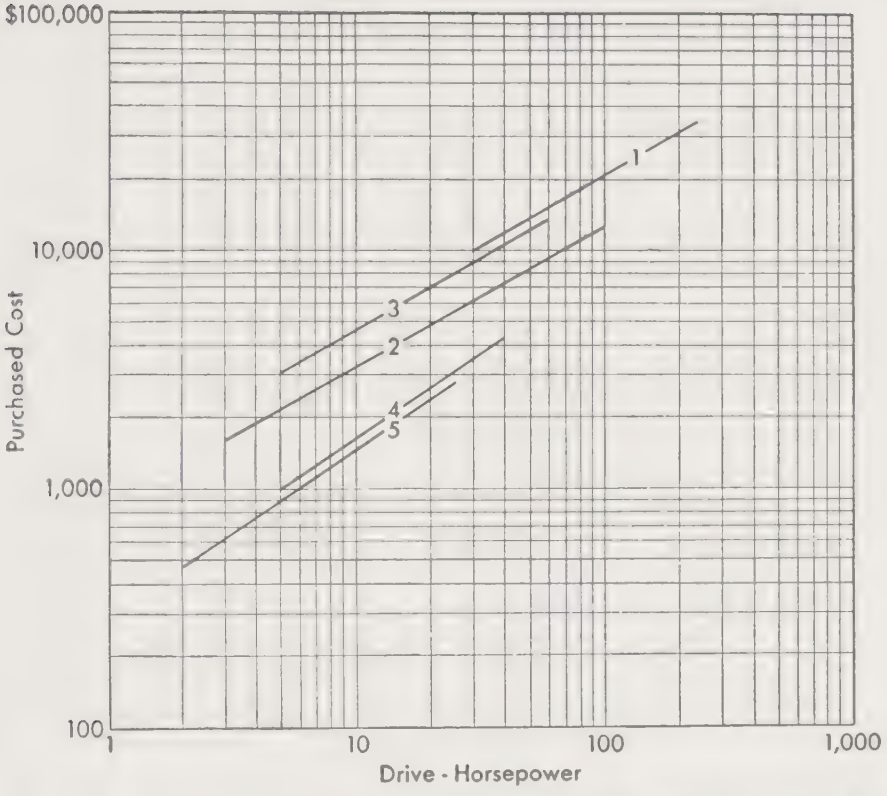


Fig. 39. Size reduction. *Crushers:* (1) gyratory, (2) jaw, (3) crushing rolls, (4) sawtooth, (5) rotary. [Refs. 2, 3, 5, 27, 28 (pp. 1120, 1125, 1127–1129), 34, 38.]

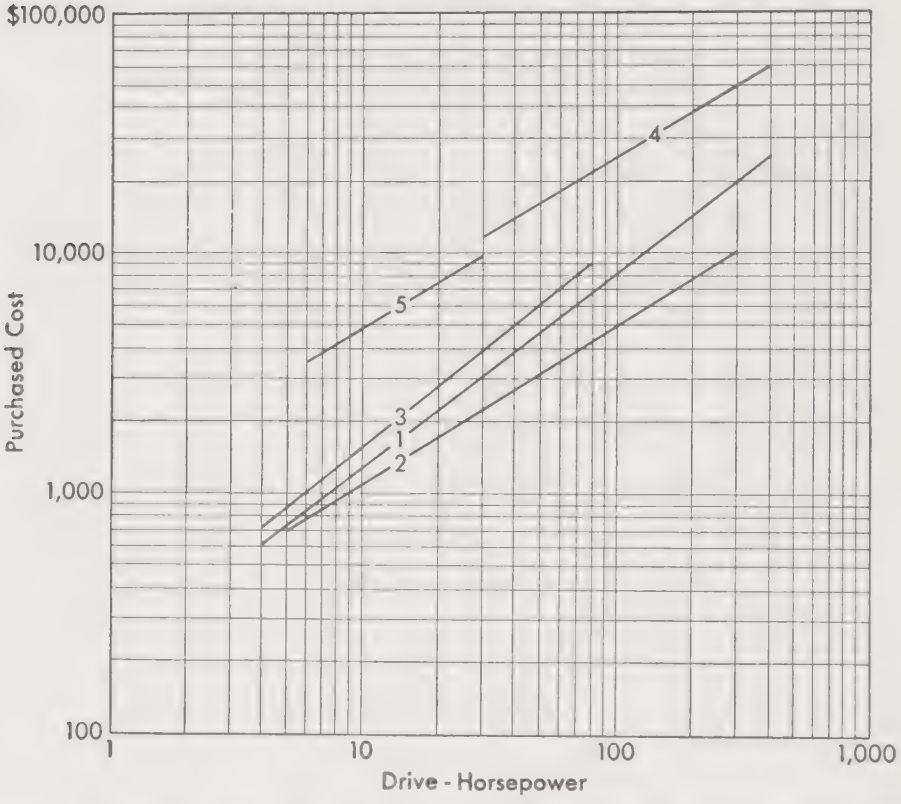


Fig. 40. Size reduction. (1) Swing-hammer mills, (2) attrition mills, (3) rotary-knife cutters, (4) roller mills, (5) Mikro-pulverizer. [Refs. 2, 3, 5, 27, 28 (pp. 1074, 1116, 1140, 1143, 1147, 1160, 1163), 34, 38.]

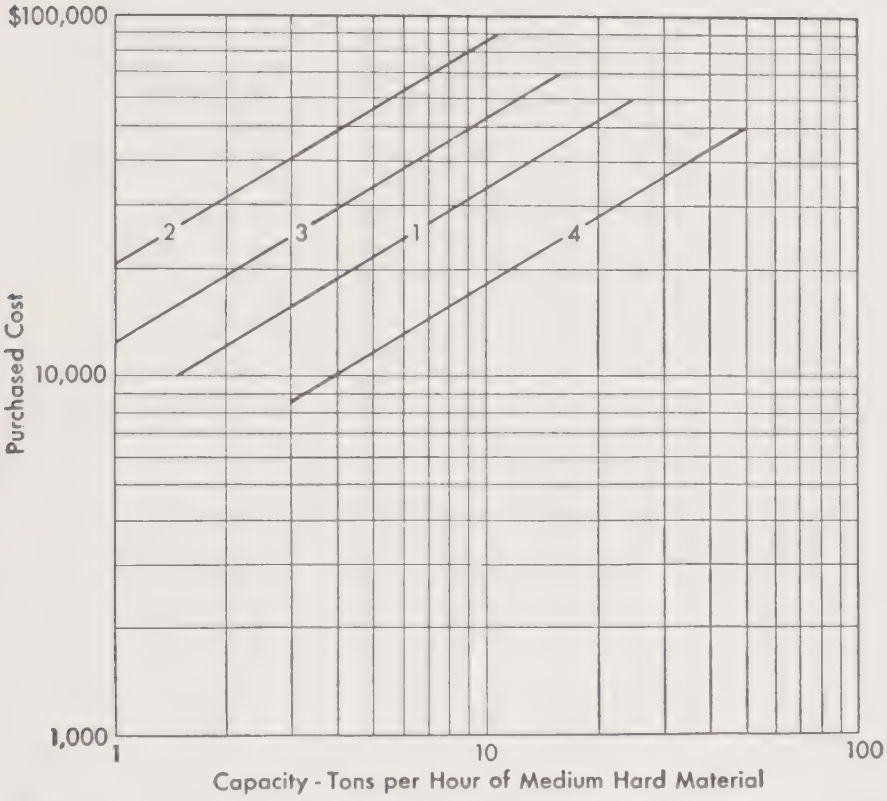


Fig. 41. Size reduction. *Ball mills:* (1) ¾ in. reduced to 48 mesh, (2) ¼ in. reduced to 98 per cent minus 325 mesh, (3) ½ in. reduced to 100 mesh, (4) 1½ in. reduced to 10 mesh. [Refs. 2, 3, 5, 27, 28 (p. 1220), 34, 38.]

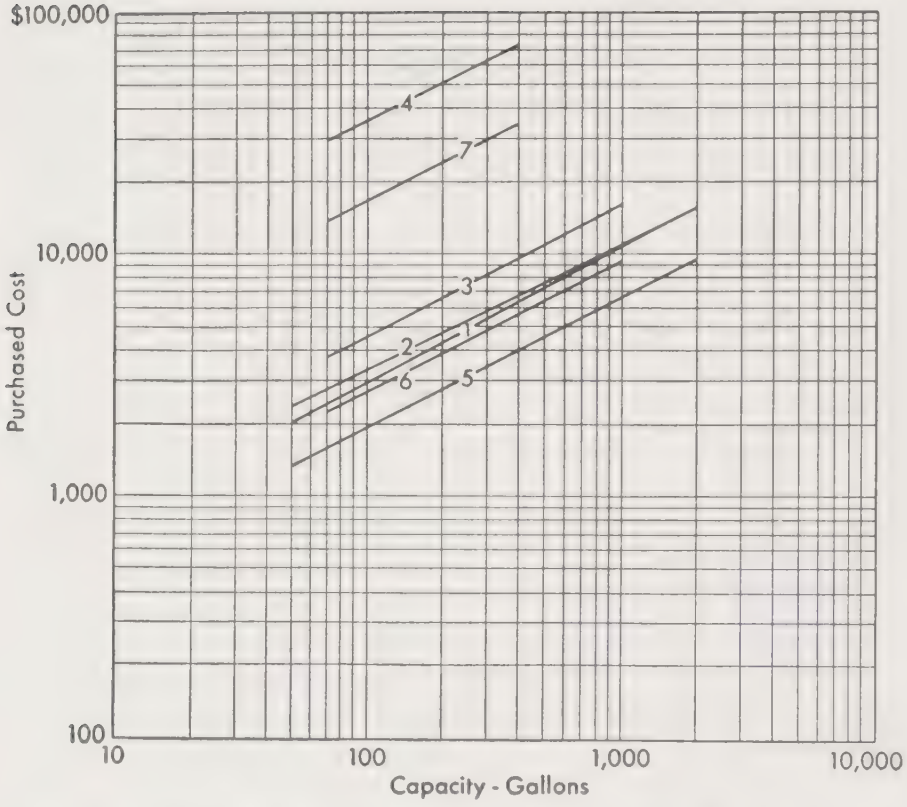


Fig. 42. Tanks. *Reactor, agitated, jacketed:* (1) glass-lined steel, 50 psi, (2) stainless steel, 50 psi, (3) stainless steel, 300 psi, (4) stainless steel, 1,500 psi, (5) steel, 50 psi, (6) steel, 300 psi, (7) steel, 1,500 psi. [Refs. 2, 3, 22, 28 (p. 1256), 34, 39.]

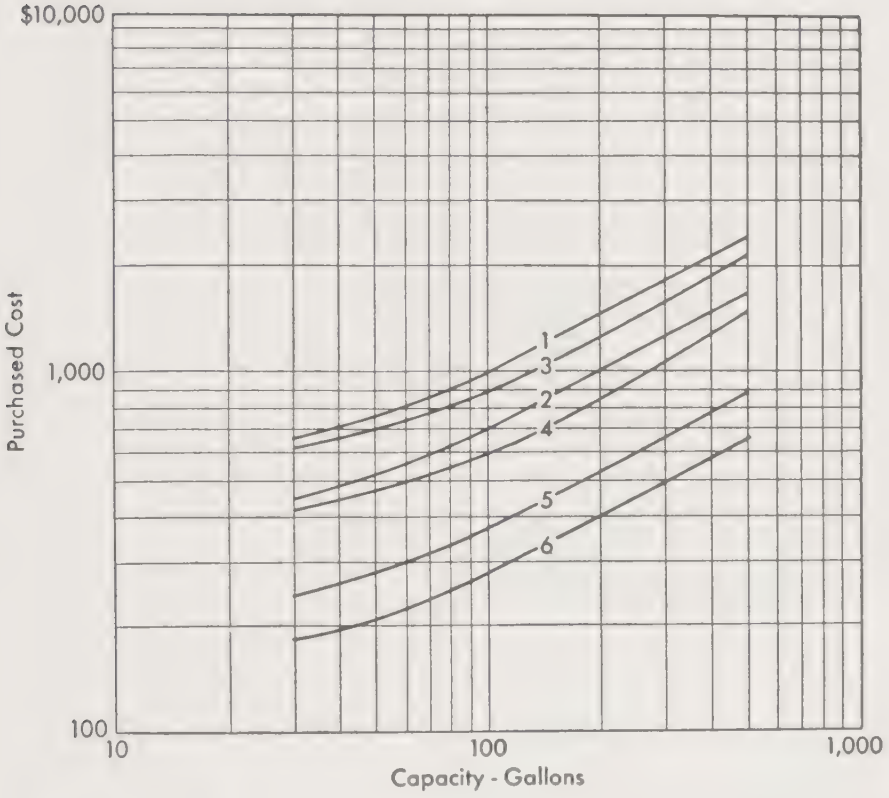


Fig. 43. Tanks. *Vacuum receiver:* (1) stainless steel, jacketed, (2) stainless steel, (3) glass lined, jacketed, (4) glass lined, (5) steel, jacketed, (6) steel. [Refs. 22, 28 (p. 990), 39.]

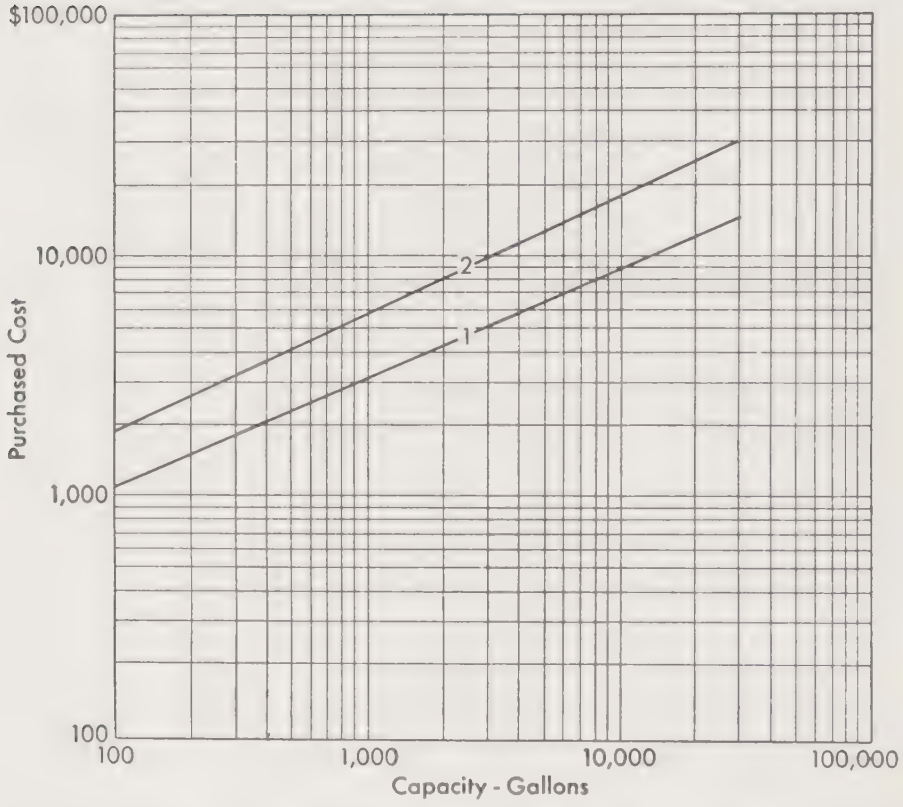


Fig. 44. Tanks. *Agitated:* (1) steel, (2) stainless steel. [Refs. 5, 6, 9, 28 (p. 1221).]

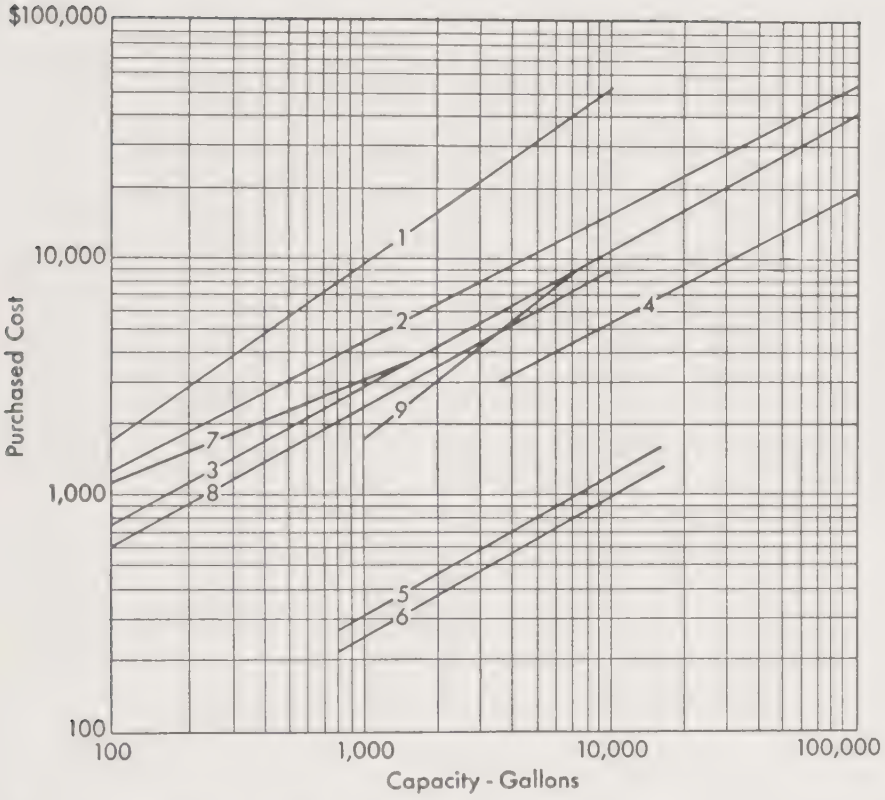


Fig. 45. Tanks. *Storage:* (1) silver-lined steel, (2) Monel, (3) aluminum, (4) Lithcote-lined steel, (5) cypress, (6) redwood, pine, fir, (7) glass-lined steel, (8) copper, (9) Haveg. [Refs. 5, 6, 9, 27, 28 (p. 1378).]

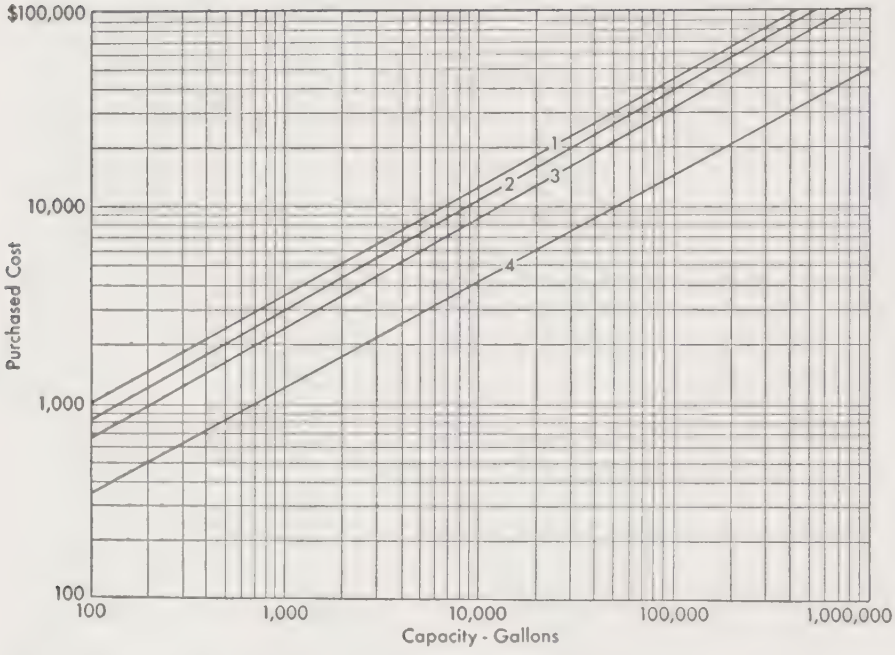


Fig. 46. Tanks. *Storage:* (1) stainless steel, Monel-clad steel, Inconel-clad steel, (2) stainless-clad steel, nickel-clad steel, (3) rubber-lined steel, (4) steel. [Refs. 5, 6, 9, 16, 27, 28 (p. 1378).]

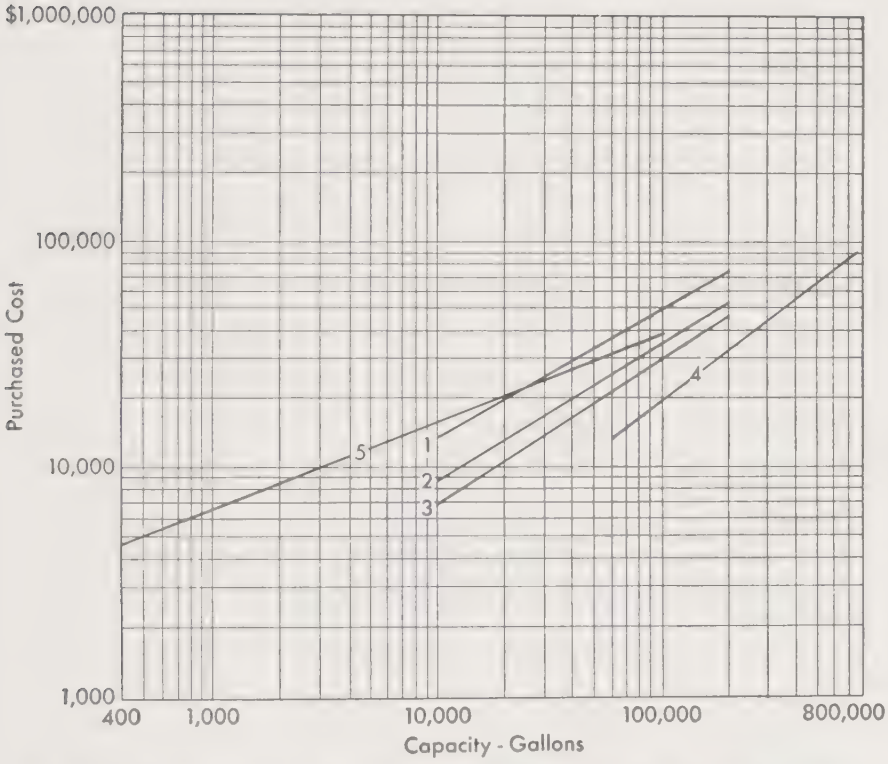


Fig. 47. Tanks. *Spheres, steel:* (1) 100 psi pressure, (2) 50 psi pressure, (3) 25 psi pressure. *Spheroids, steel, 15 psi pressure:* (4). *Cylindrical, steel, 50 to 150 psi pressure:* (5). [Refs. 5, 9, 19, 27, 28 (p. 1378).]



Fig. 48. Tanks. Gas holder. [Refs. 5, 9, 19, 27, 28 (p. 1380).]

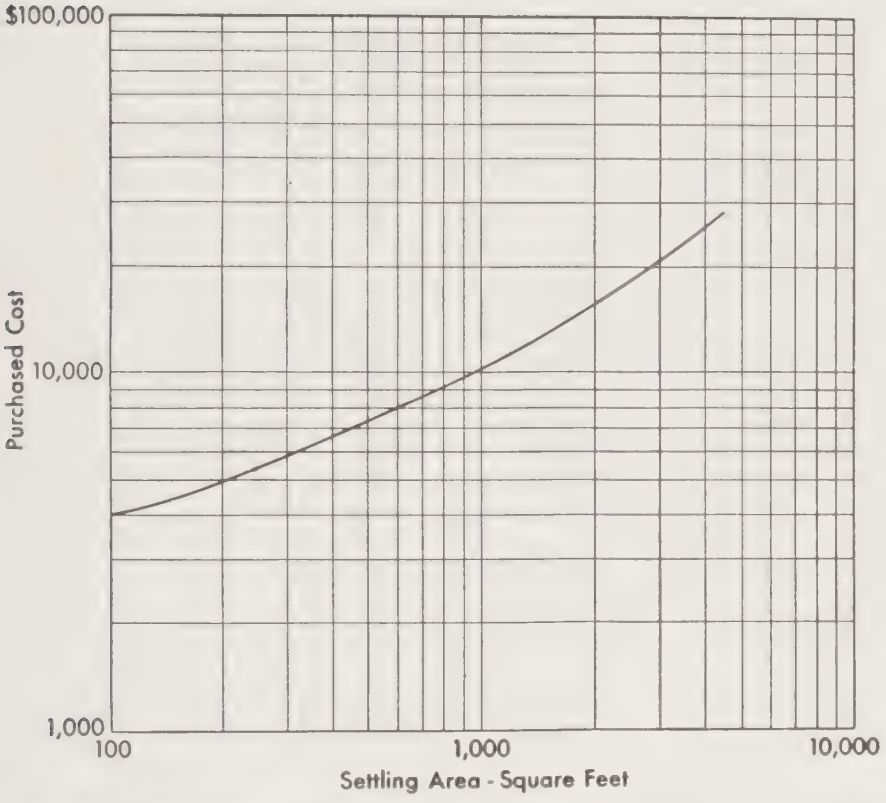


Fig. 49. Thickeners. Continuous. [Refs. 2, 3, 5, 27, 28 (p. 941), 34, 38.]

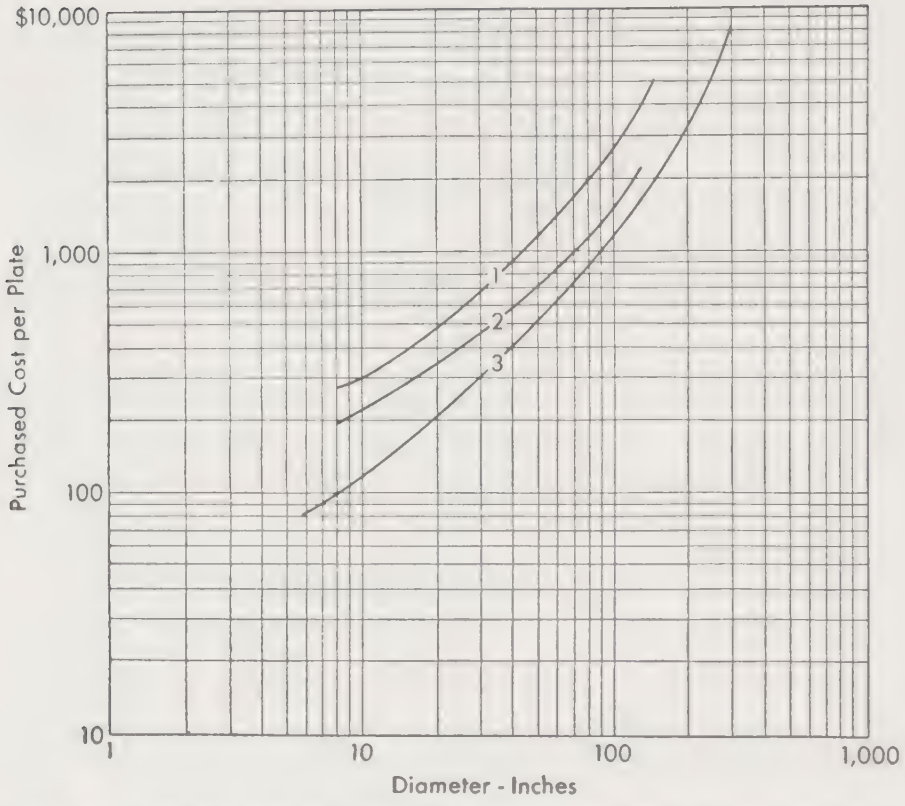


Fig. 50. Towers. *Bubble plate:* (1) stainless steel, (2) copper, (3) steel. [Refs. 2, 3, 5, 15, 18, 27, 28 (p. 596).]

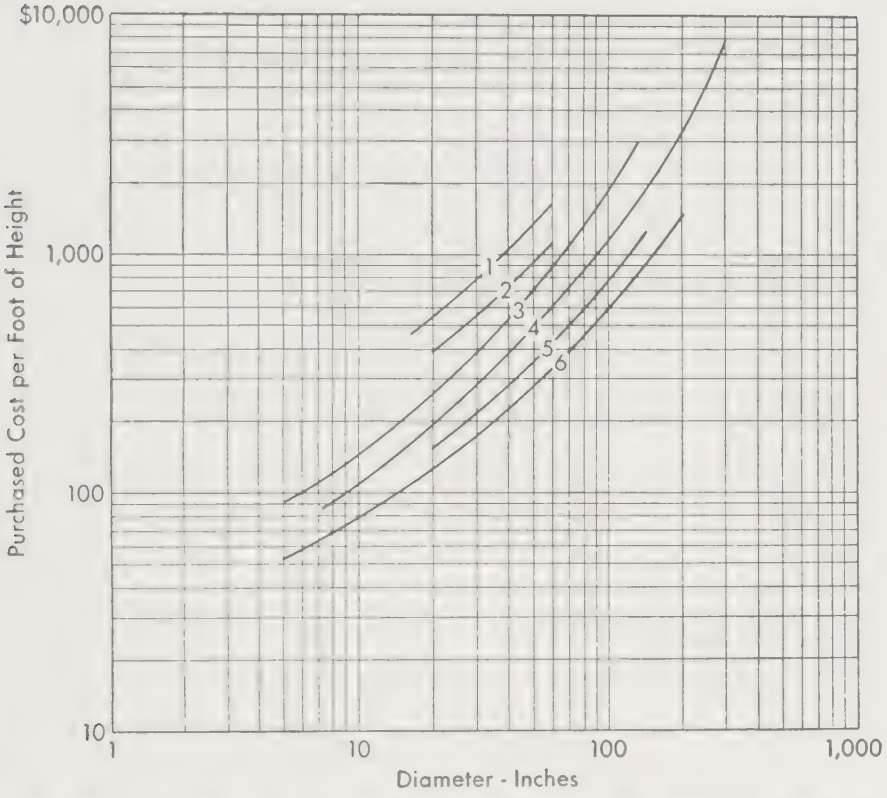


Fig. 51. Towers. *Packed:* (1) silver-lined steel, (2) glass-lined steel, (3) stainless steel, (4) copper, (5) Haveg, (6) steel. [Refs. 2, 3, 5, 15, 18, 27, 28 (p. 596).]

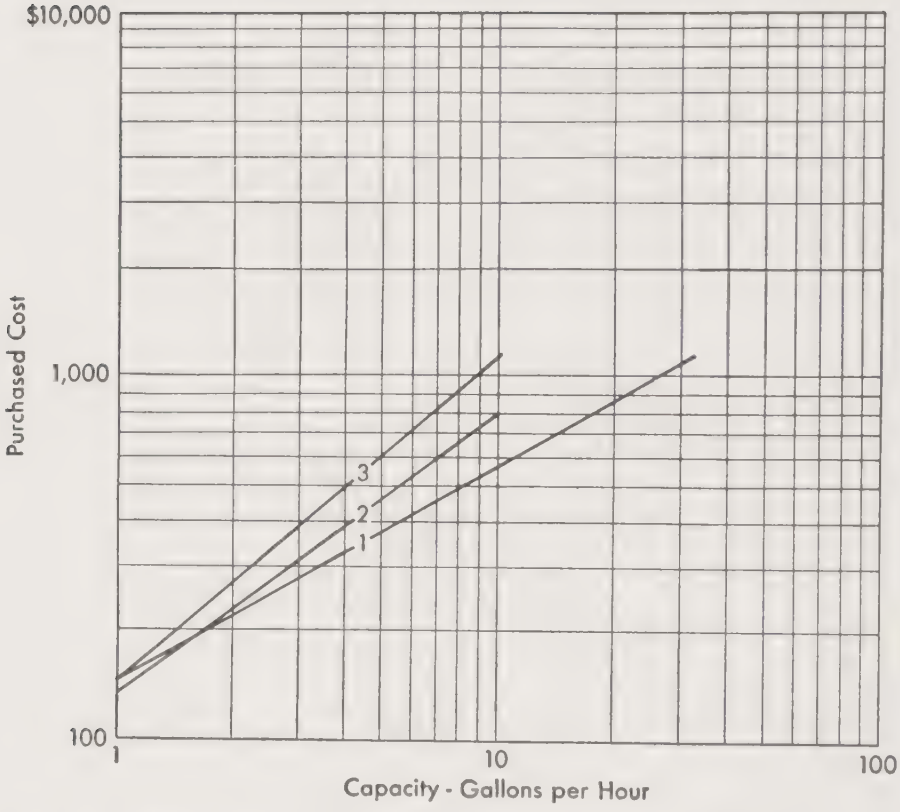


Fig. 52. Water stills. (1) Steam, (2) gas, (3) electric. [Ref. 39.]

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3. PHYSICAL-PLANT COST: COMPONENTS OTHER THAN EQUIPMENT

While the purchased cost of process equipment is the most important component of physical-plant cost to the estimator, it represents but a fraction of the total. The elements of installation, piping, instrumentation, insulation, and electrical auxiliaries, which transform a piece of equipment into a productive unit, must be considered. In addition to these requirements, building, utility, land, and yard-improvement needs must be assayed. In the subsequent sections, data are presented which will enable the calculation of each of these components independently as demanded by the use of Method 1 (Chap. 1) for capital-cost estimation. Furthermore, percentage values, equivalent to the purchased-equipment cost, are shown for use of Method 2.

Equipment Installation

The cost of installing process equipment may be subdivided into three primary components: foundations, platforms and supports, and erection. Foundation and platform and support costs will be found in Table 14. While the actual cost of labor for erection of equipment can be determined only from experience, a value equivalent to 25 per cent of the purchased price of equipment may be used for estimating.[2, 17, 19, 20, 25, 37]

Table 14. Foundation and Platform and Support Costs

	Material	Labor	Total
Foundations:			
Small excavations, per cu yd	.....	$ 2.00	$ 2.00
Small concrete foundations, per cu yd	$ 15.00	15.00	30.00
Concrete encasing columns, per cu yd	26.00	23.00	49.00
Platforms and supports:			
Structural steel, per lb	0.15	0.06	0.21
Stairways and railings, per ft	35.00	8.00	43.00
Ladders with supports, per ft	8.00	2.00	10.00
Walkways, 3 ft, per ft	15.00	5.00	20.00
Handrails, per ft	2.00	0.65	2.65
Gratings, per sq ft	1.50	0.30	1.80
Wood scaffoldings, per 1,000 fbm	150.00	150.00	300.00

Table 15. Total Installation Cost

(Equivalent to percentages of purchased-equipment cost)

Type of equipment	*Installation cost, %*
Evaporators	10–30
Heat exchangers	5–20
Mixers	5–15
Metal tanks	20–40
Wood tanks	30–60
Vacuum crystallizers	40–55
Mechanical crystallizers	30–50
Centrifugal separators	10–25
Compressors	20–60
Pumps	5–20
Towers	25–50
Filters	25–45
Dryers	30–60

The total installation expenses for various pieces of equipment are given in Table 15 as equivalents to percentages of the purchase prices.

The installation cost of process equipment may be computed as being an amount equivalent to 43 per cent of the purchased-equipment cost. Further division may be made based upon the listing in Table 16.

Table 16. Installation Costs
(Equivalent to percentages of purchased-equipment cost)

	Material, %	Labor, %	Total, %
Foundations	4	3	7
Platforms and supports	7	4	11
Erection of equipment	..	25	25
Total installation	11	32	43

Piping

Piping cost is perhaps the most difficult phase of capital-cost estimating and yet, because of its magnitude, it is of great importance. Use of Figs. 54 to 69, which are adaptations of Dickson's original "N"-factor system, will eliminate the need for detailed piping specifications but will still preserve a high degree of accuracy. Each of these graphs shows the purchased price of 1 ft of pipe, one representative fitting calculated as a tee, and one valve, generally a gate, at various diameters for a wide selection of schedules and materials. In addition, the cost of labor in piping erection is noted as an equivalent percentage of the material cost; where a range of percentage erection charges is found, the smaller ones apply to the larger diameters of pipe, and vice versa. To employ this method,

the size of pipe must be determined from Fig. 53, which shows the variation in diameter with fluid density and flow. With the size and service selected, the unit costs are located on the proper graph and multiplied respectively by the footage of pipe, the number of fittings, and the number of valves required.

Table 17. Piping Cost

(Equivalent to percentages of purchased-equipment cost)

Process	Material, %	Labor, %	Total, %
Solid	8	6	14
Solid-fluid	21	15	36
Fluid	49	37	86

To each of the resultant three purchased costs—pipe, fittings, and valves—the installation cost is added to obtain the total piping cost.[3–5, 9–11, 15, 21, 24, 32, 34, 37]

The cost of piping, depending upon the type of process involved, may be estimated at amounts equal to percentages of the purchased-equipment value.

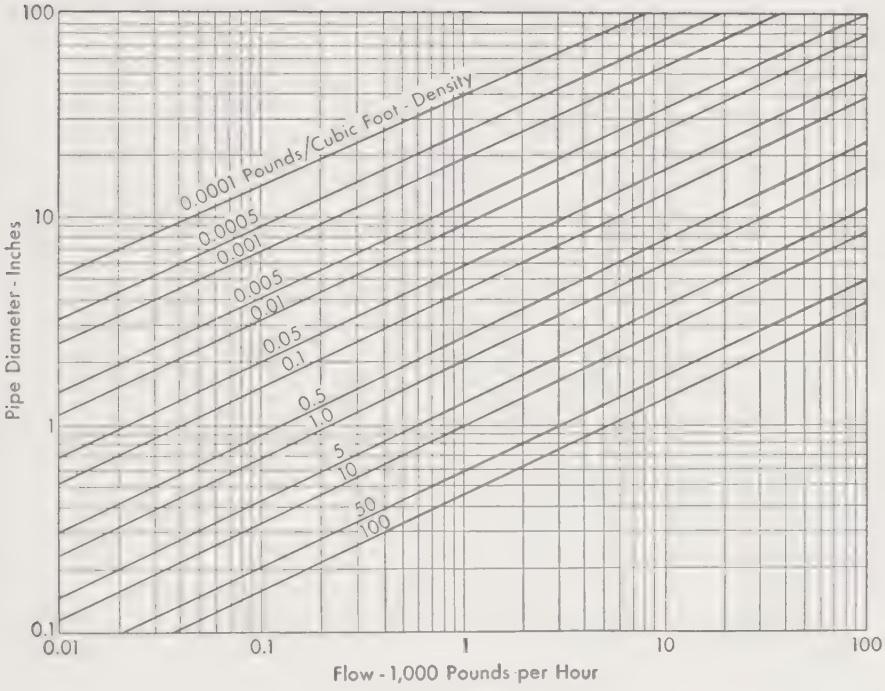


Fig. 53. Economic pipe diameter. [Ref. 31.]

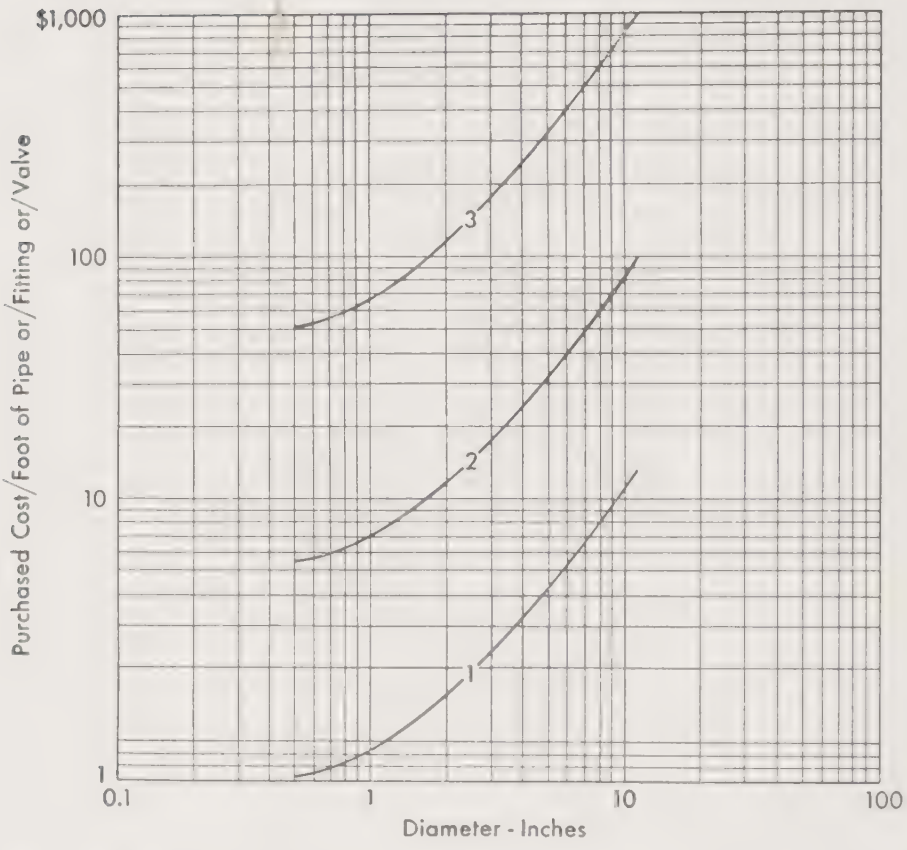


Fig. 54. Pipe, aluminum. (1) Pipe (5 per cent of material cost equals installation), (2) fitting (46 per cent of material cost equals installation), (3) valve (9 per cent of material cost equals installation).

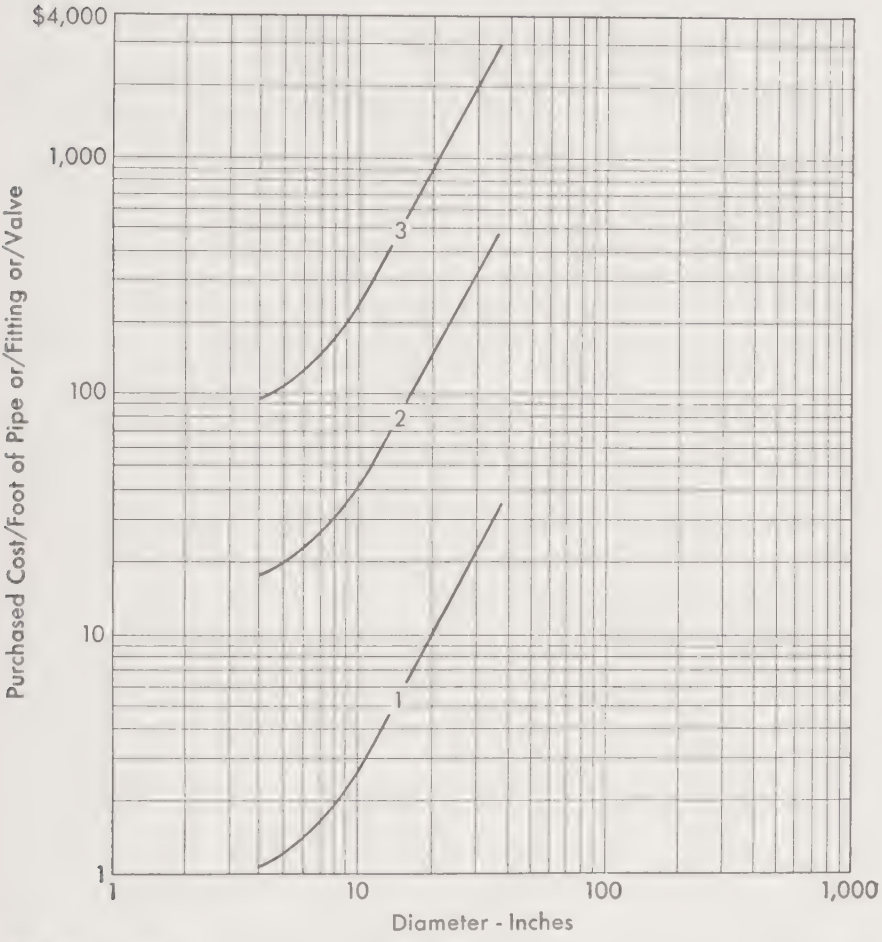


Fig. 55. **Pipe, asbestos cement.** (1) Pipe (5 per cent of material cost equals installation), (2) fitting, cast iron (21 per cent of material cost equals installation), (3) valve, cast iron (9 per cent of material cost equals installation).

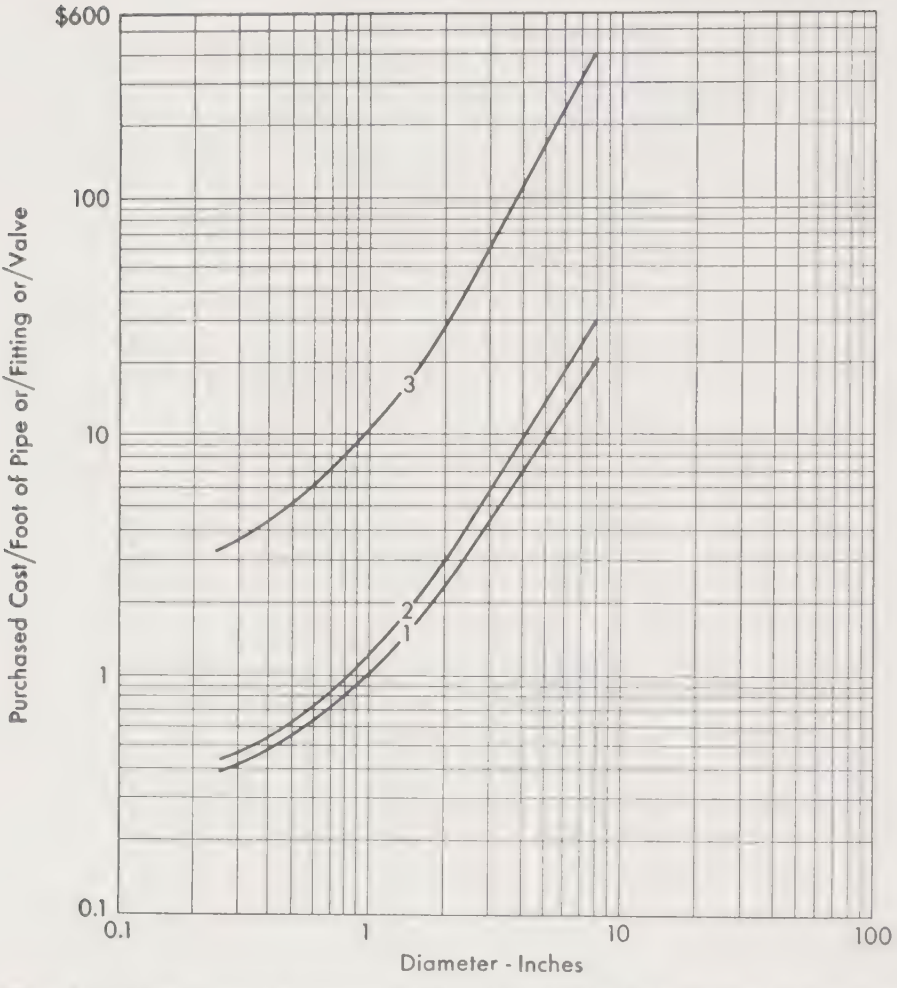


Fig. 56. Pipe, brass, standard weight. (1) Pipe (6 to 9 per cent of material cost equals installation), (2) fitting (20 to 100 per cent of material cost equals installation), (3) valve (15 to 20 per cent of material cost equals installation).

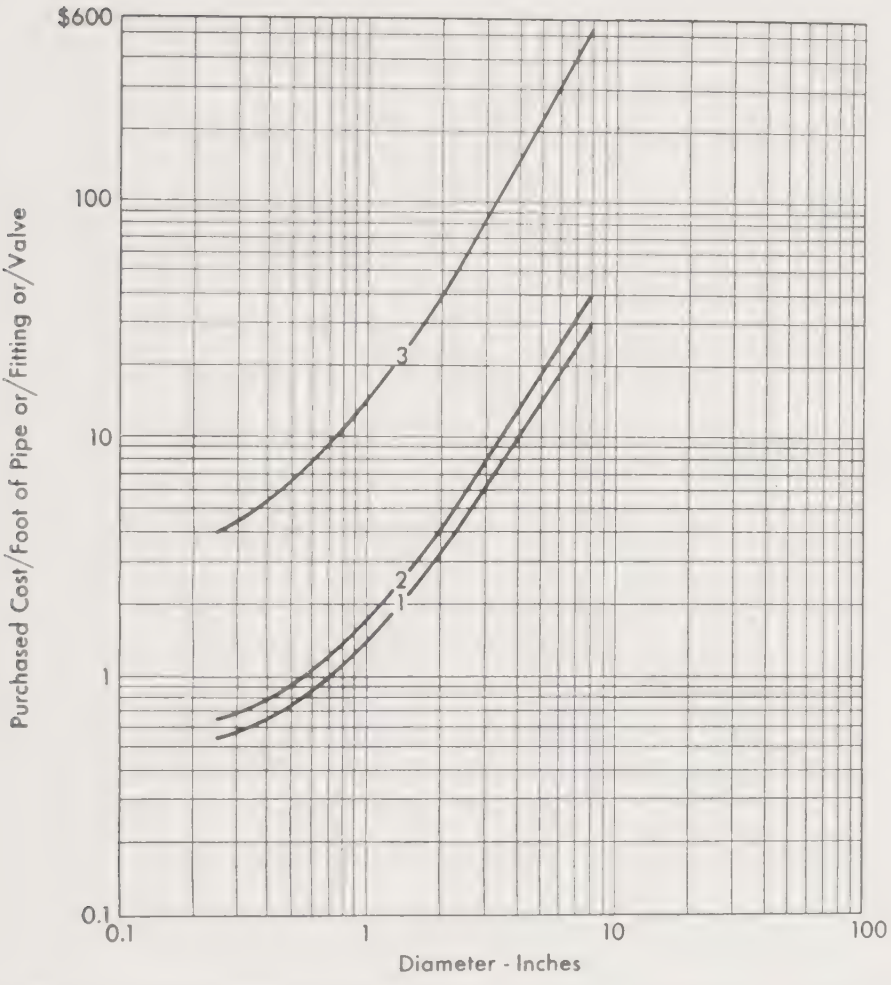


Fig. 57. Pipe, brass, extra-heavy. (1) Pipe (4 to 5 per cent of material cost equals installation), (2) fitting (10 to 60 per cent of material cost equals installation), (3) valve (5 to 12 per cent of material cost equals installation).

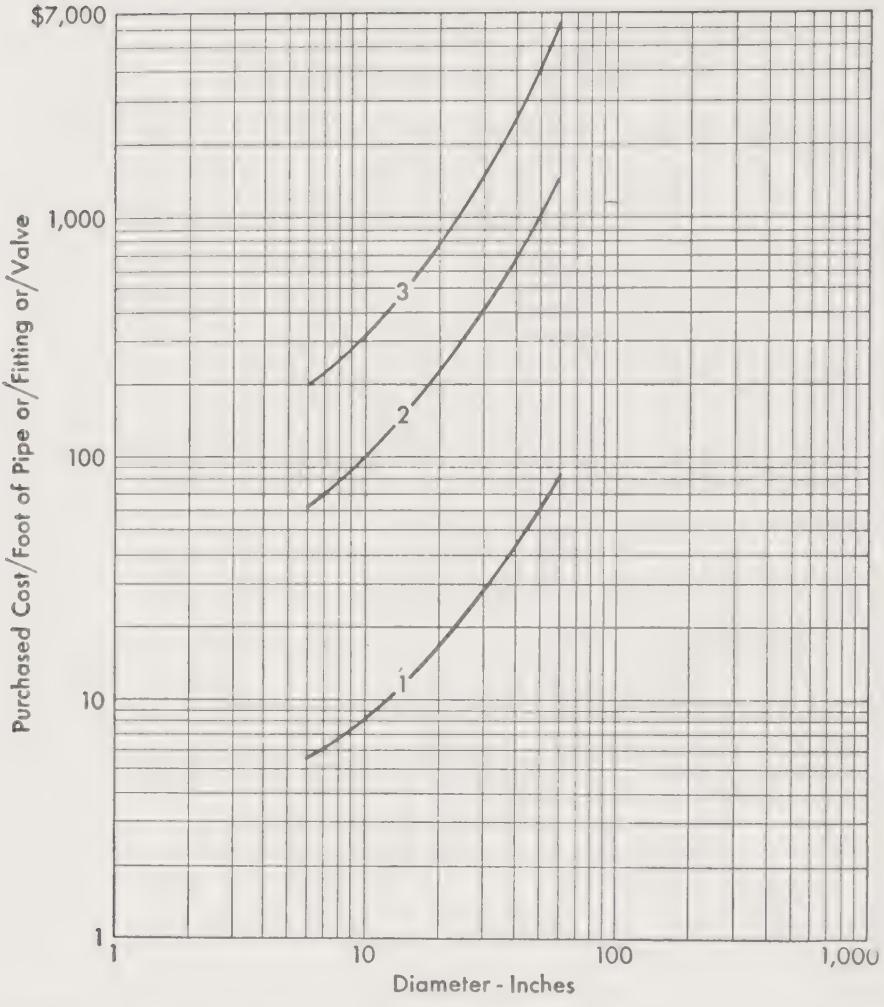


Fig. 58. Pipe, cast iron. (1) Pipe (35 to 75 per cent of material cost equals installation), (2) fitting (25 to 40 per cent of material cost equals installation), (3) valve (10 to 50 per cent of material cost equals installation).

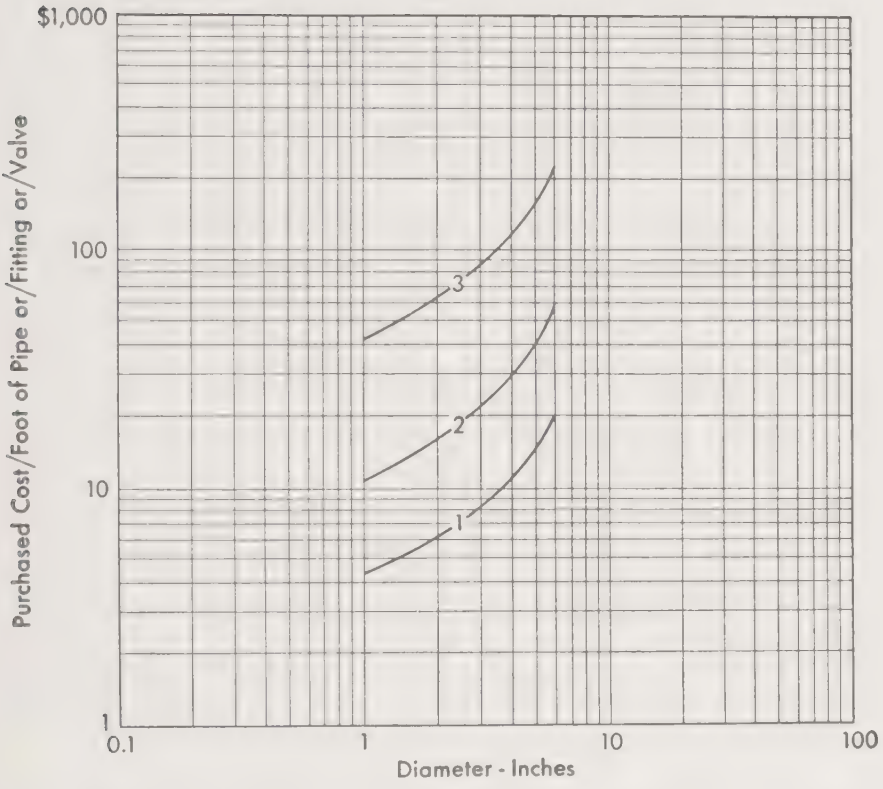


Fig. 59. Pipe, Duriron. (1) Pipe (30 per cent of material cost equals installation), (2) fitting (125 per cent of material cost equals installation), (3) valve (25 per cent of material cost equals installation).

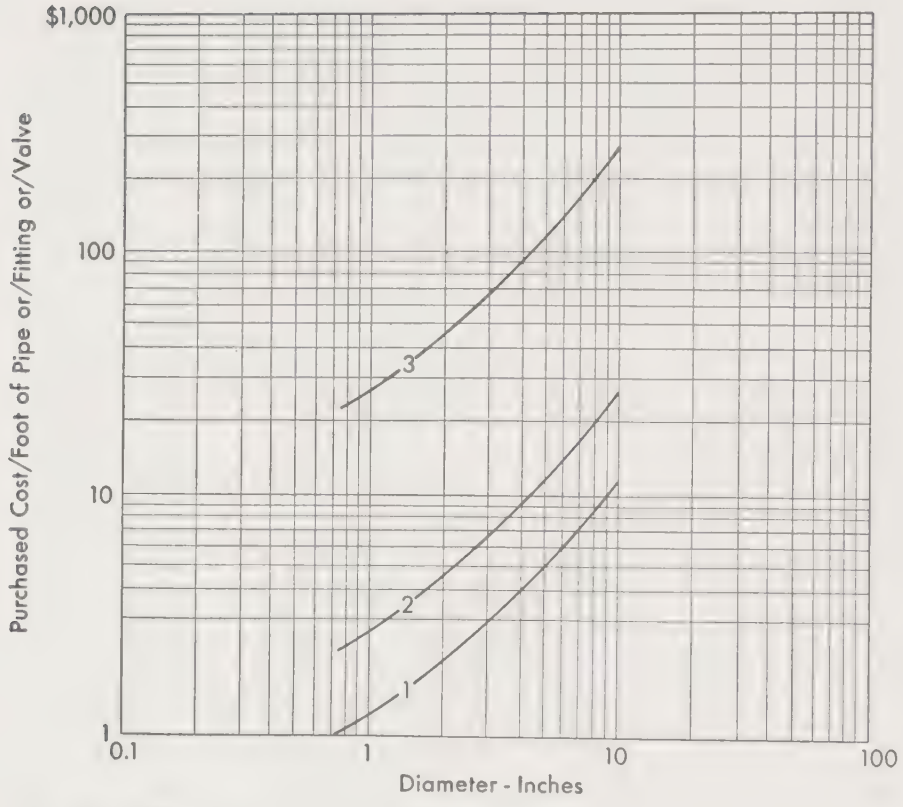


Fig. 60. Pipe, lead. (1) Pipe (50 per cent of material cost equals installation), (2) fitting (115 per cent of material cost equals installation), (3) valve (13 per cent of material cost equals installation).

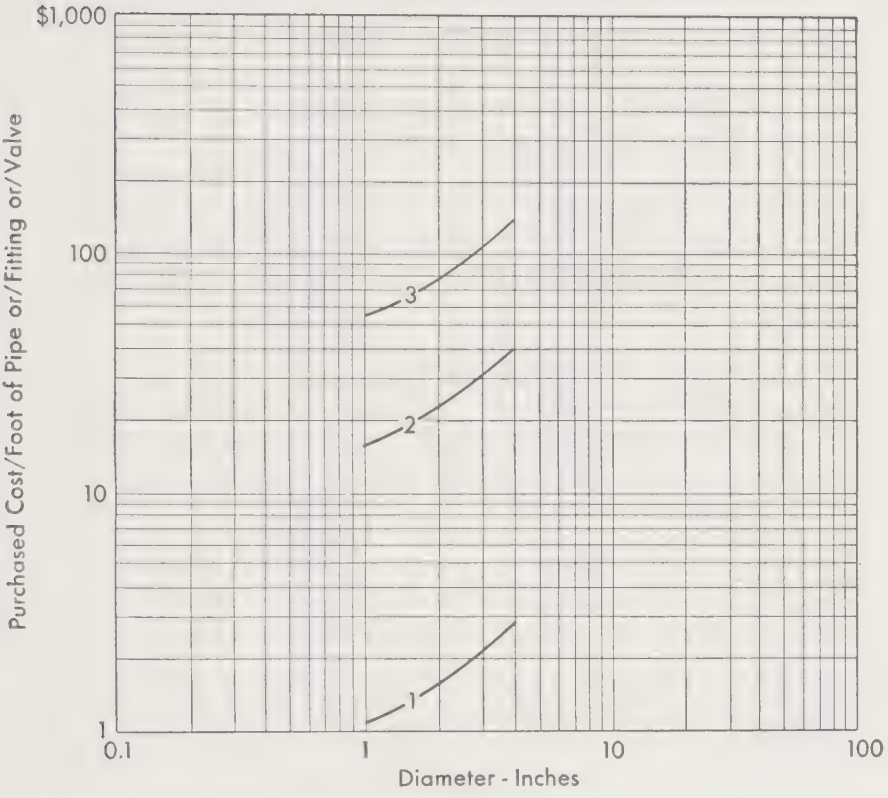


Fig. 61. Pipe, Pyrex glass. (1) Pipe (15 per cent of material cost equals installation), (2) fitting (75 per cent of material cost equals installation), (3) valve, 316 stainless steel (15 per cent of material cost equals installation).

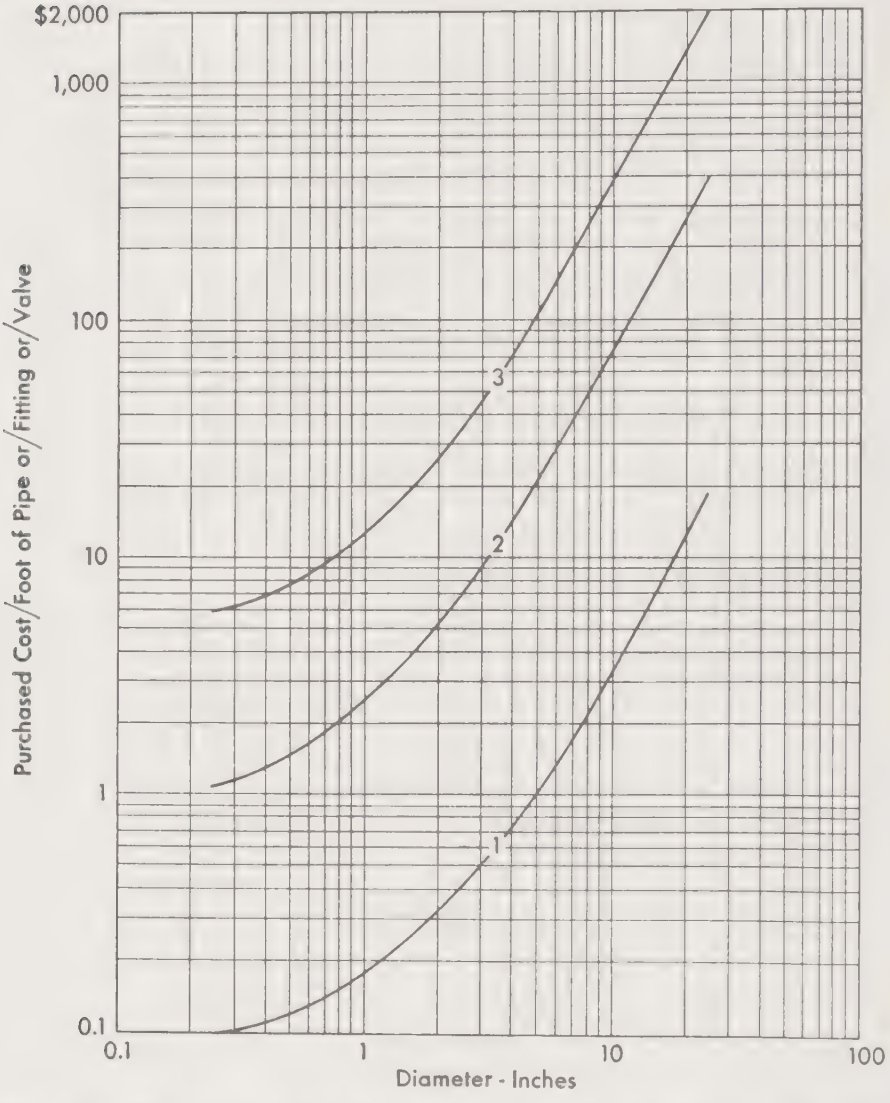


Fig. 62. Pipe, steel, black, standard weight. (1) Pipe (25 to 30 per cent of material cost equals installation), (2) fitting (20 to 100 per cent of material cost equals installation), (3) valve (15 to 40 per cent of material cost equals installation).

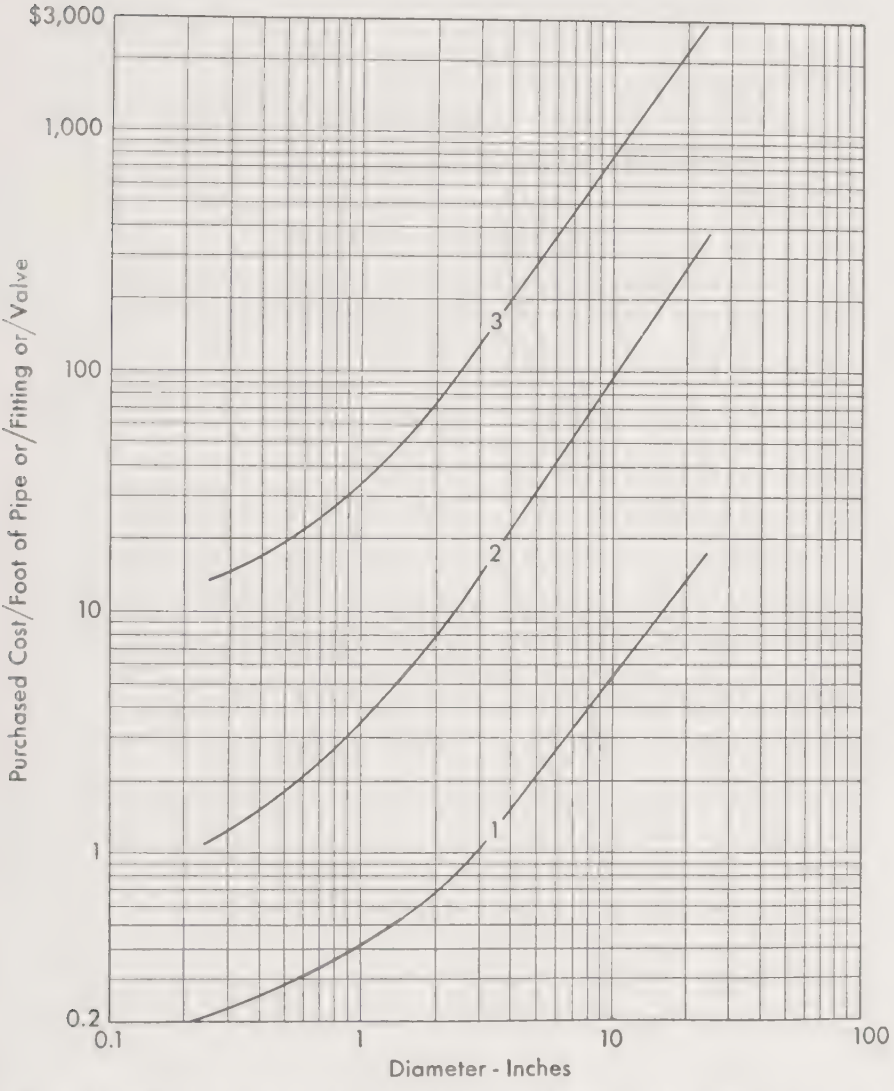


Fig. 63. Pipe, steel, black, extra-heavy. (1) Pipe (15 to 30 per cent of material cost equals installation), (2) fitting (25 to 100 per cent of material cost equals installation), (3) valve (10 to 15 per cent of material cost equals installation).

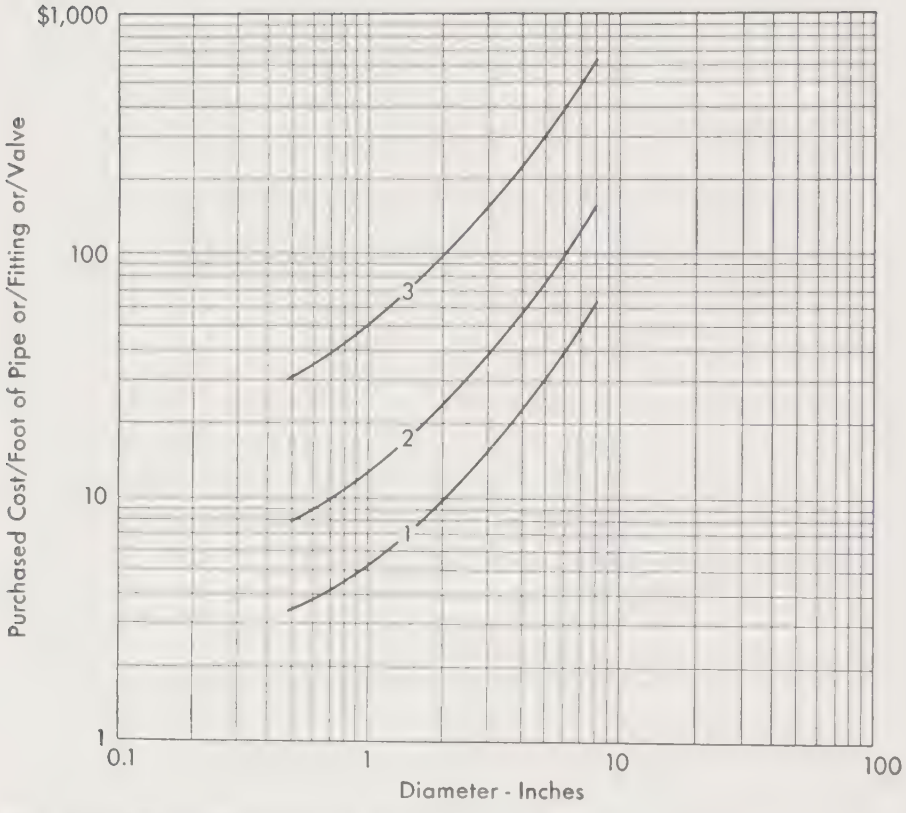


Fig. 64. Pipe, 304 stainless steel, standard weight. (1) Pipe (2 per cent of material cost equals installation), (2) fitting (25 per cent of material cost equals installation), (3) valve (10 per cent of material cost equals installation).

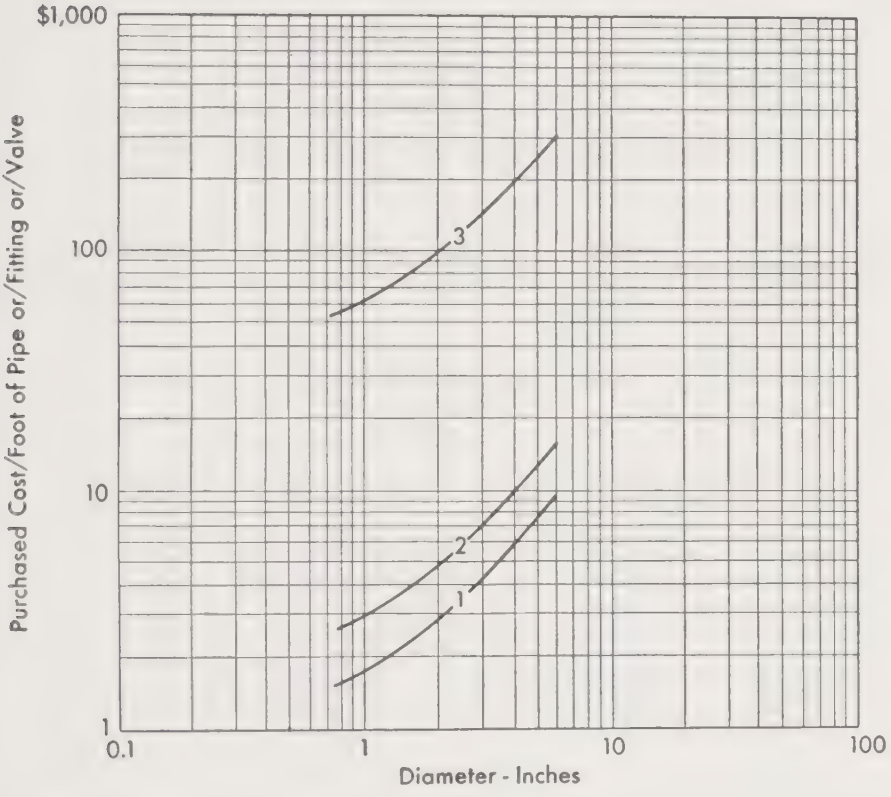


Fig. 65. Pipe, 304 stainless steel, zephyr weight. (1) Pipe (3 per cent of material cost equals installation), (2) fitting (100 per cent of material cost equals installation), (3) valve (10 per cent of material cost equals installation).

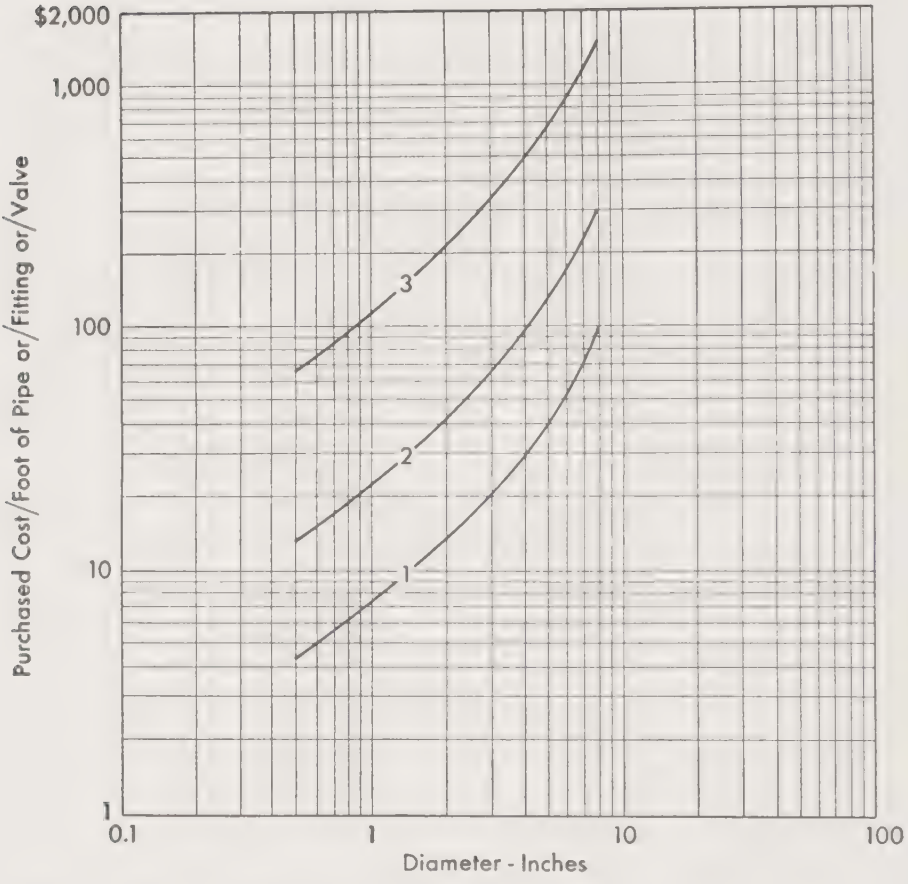


Fig. 66. Pipe, 304 stainless steel, extra heavy. (1) Pipe (1 per cent of material cost equals installation), (2) fitting (13 per cent of material cost equals installation), (3) valve (6 per cent of material cost equals installation).

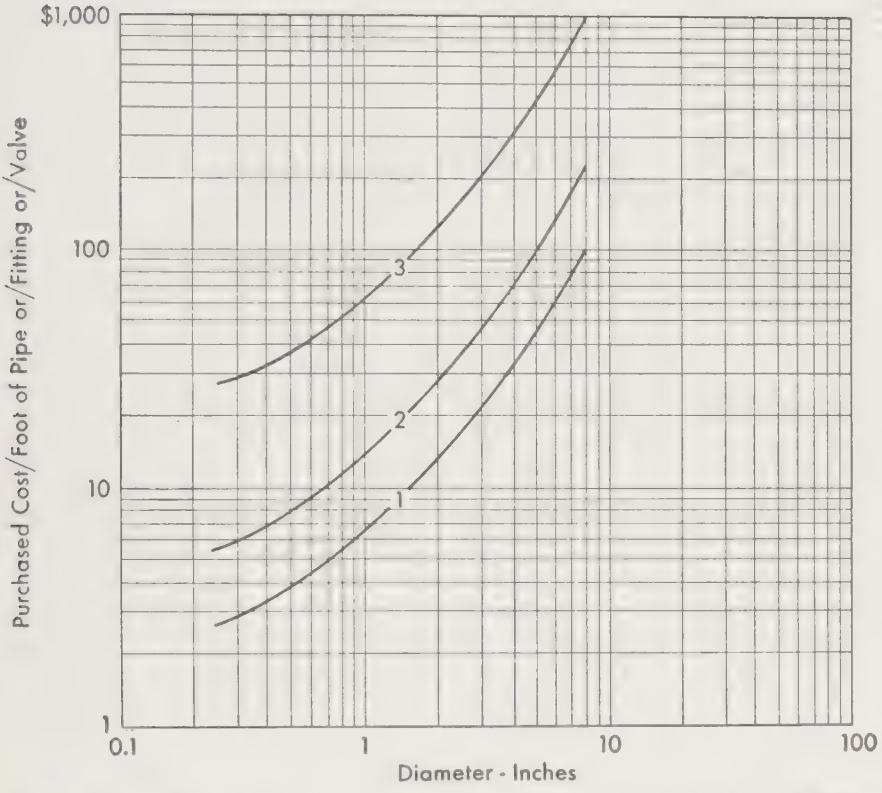


Fig. 67. Pipe, 316 or 347 stainless steel, standard weight. (1) Pipe (2 per cent of material cost equals installation), (2) fitting (20 to 100 per cent of material cost equals installation), (3) valve (5 to 10 per cent of material cost equals installation).

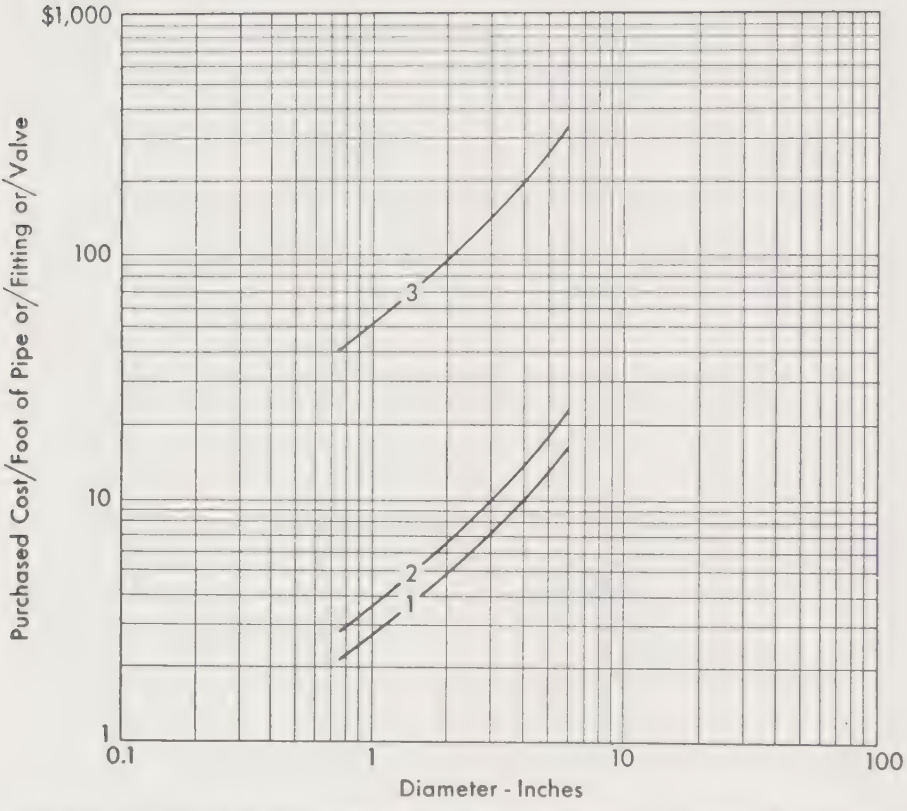


Fig. 68. Pipe, 316 stainless steel, zephyr weight. (1) Pipe (2 per cent of material cost equals installation), (2) fitting (62 per cent of material cost equals installation), (3) valve (9 per cent of material cost equals installation).

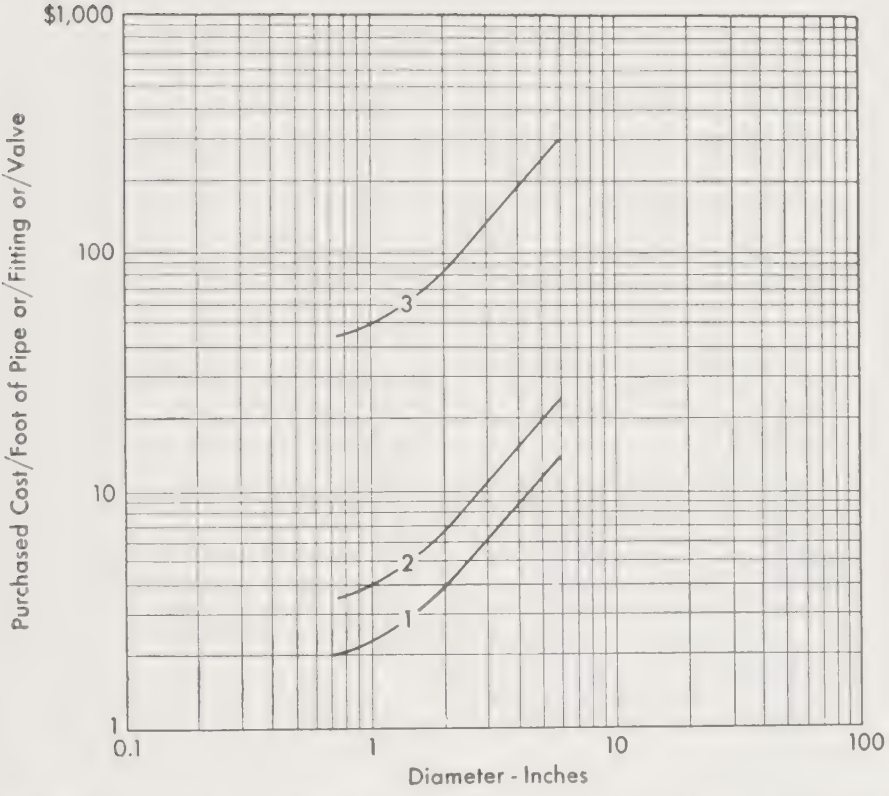


Fig. 69. **Pipe, 347 stainless steel, zephyr weight.** (1) Pipe (2 per cent of material cost equals installation), (2) fitting (66 per cent of material cost equals installation), (3) valve (9 per cent of material cost equals installation).

Instrumentation

From instrumentation schedules the cost of instruments may be calculated by using the purchased prices listed in Table 18,

Table 18. Purchased Costs of Instruments and Auxiliaries

Instrument	*Cost*
Temperature:	
Industrial thermometer	$ 30
Indicating thermometer	120
Recording thermometer	190
Recording-controlling thermometer	550
Indicating pyrometer	250
Recording pyrometer	500
Recording-controlling pyrometer	850
Multipoint recording pyrometer	1,100
Multipoint recording-controlling pyrometer	1,300
Pressure:	
Indicating	50
Recording	160
Recording-controlling	480
Liquid level:	
Sight glass	70
Indicating	160
Recording	260
Recording-controlling	600
Flow:	
Indicating manometer	200
Recording manometer	420
Recording-controlling manometer	750
Indicating rotameter (less than 250 gpm)	150
Indicating rotameter (greater than 750 gpm)	320
Recording rotameter	450
Recording-controlling rotameter	750
Displacement meter	250

which includes not only the instruments but also all auxiliaries for a complete system. To cover installation expense, an additional 25 per cent must be added to the purchased cost.[8, 16, 25, 38]

Where tolerances on pressure, temperature, etc., are small, as in distillations, extractions, or reactions, extensive automatic instrumentation is required. On the other hand, mixing, filtration, and size-reduction operations need few controls. It should be noted that for any particular process the cost of instrumentation will vary roughly as the 0.3 power of the plant capacity.

Instrumentation costs may be calculated from the purchased-equipment cost as equivalent percentages, depending upon the degree of automatic control employed.

Table 19. Instrumentation Cost

(Equivalent to percentages of purchased-equipment cost)

	Material, %	Labor, %	Total, %
Few or no controls.....	4	1	5
Some specific controls...	12	3	15
Extensive controls.....	24	6	30

Insulation

The cost of insulating equipment may be determined from Table 20. Piping-insulation costs are estimated from Figs. 70 to 72, which show costs at various diameters.[16, 25–28, 37]

Table 20. Insulation Costs per Square Foot

Insulation	Material	Labor	Total
Corkboard:			
1 in.	$0.18	$0.70	$0.88
2 in.	0.35	0.70	1.05
Cork lagging:			
1 in.	0.36	1.00	1.36
2 in.	0.55	1.00	1.55
4 in.	0.96	1.20	2.16
Magnesia blocks:			
1 in.	0.35	1.40	1.75
2 in.	0.70	1.50	2.20
Mineral-wool blankets:			
1 in.	0.40	1.00	1.40
2 in.	0.60	1.00	1.60
4 in.	0.80	1.20	2.00
Mineral-wool blocks:			
1 in.	0.30	1.40	1.70
2 in.	0.60	1.50	2.10

The expense of insulating equipment and piping may be approximated as an amount equal to 8 per cent of the purchased-equipment cost.

Table 21. Insulation Cost

(Equivalent to percentages of purchased-equipment cost)

	Material, %	Labor, %	Total, %
Insulation	3	5	8

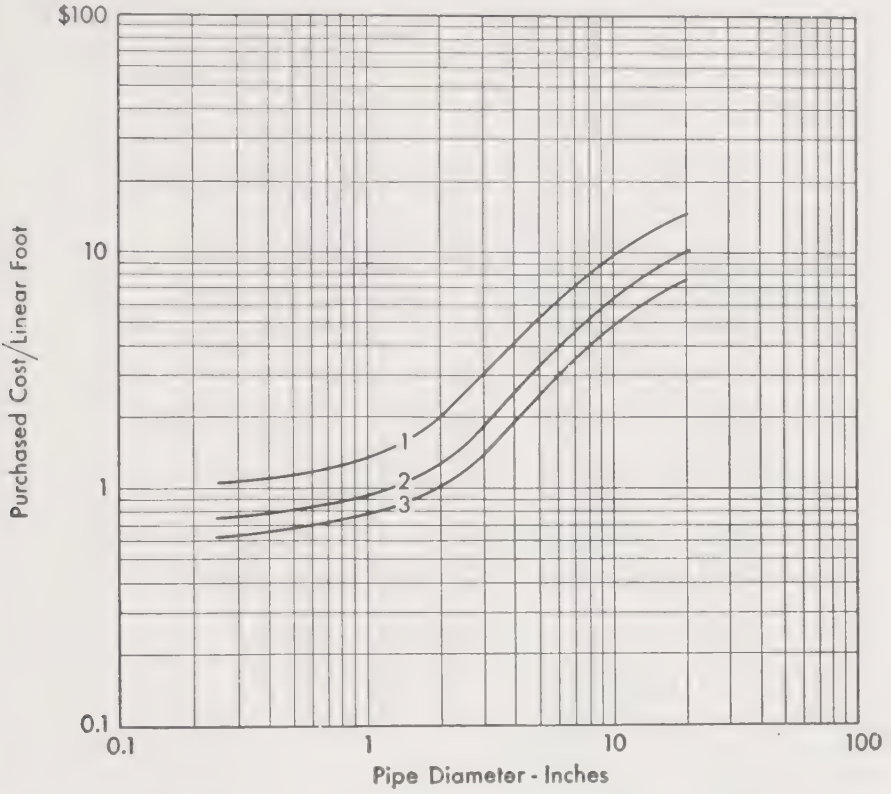


Fig. 70. Insulation, cork. (1) Special thick brine, 0 to −25°F, (2) brine thickness, 0 to 35°F, (3) ice-water thickness, above 35°F.

Purchased Cost of Molded Cork Covers per Fitting *

Pipe diameter, in.	Screwed, %	Flanged, %
¼	130	400
1	150	500
6	200	700

* Cost equivalent to 1 ft of pipe insulation.

Installation cost equals 60 to 70 per cent of material cost.

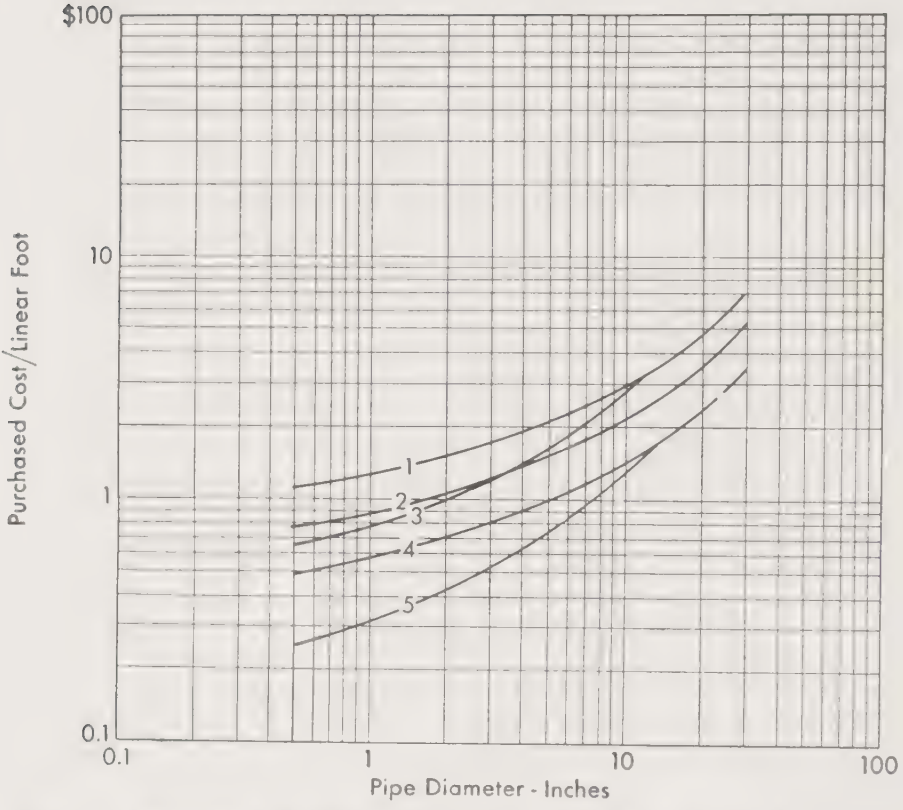


Fig. 71. Insulation, 85 per cent magnesia. (1) 3 in. thick, (2) 2 in. thick, (3) double standard, (4) 1½ in. thick, (5) standard. Installation cost equals 150 to 250 per cent of material cost for (4) and (5), and 100 to 125 per cent of material cost for (1), (2), and (3).

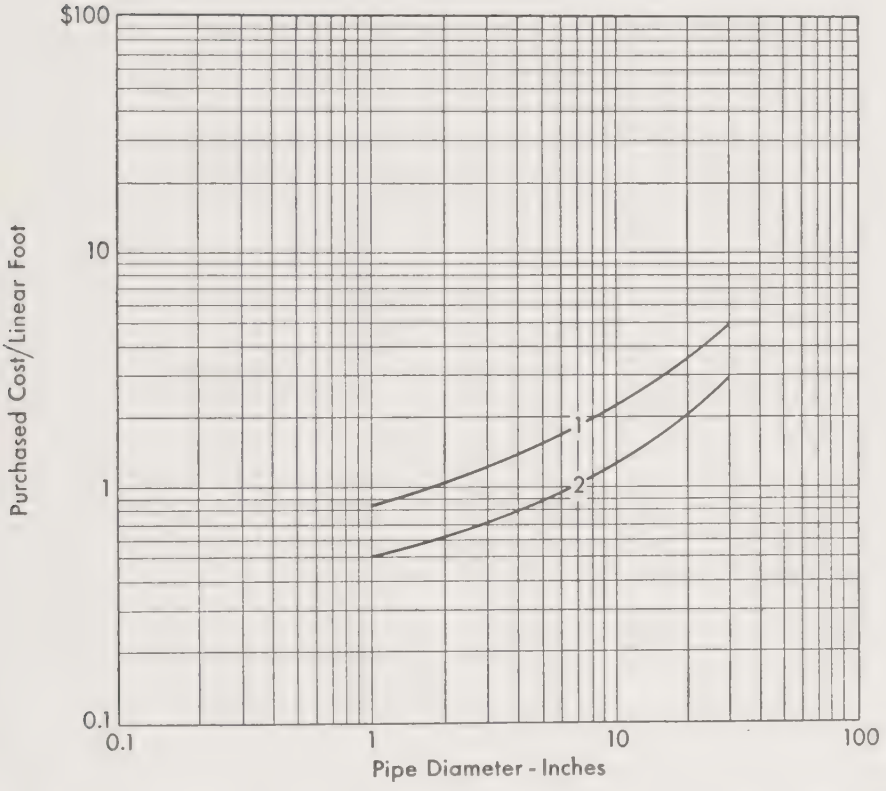


Fig. 72. Insulation, mineral wool. (1) 2 in. thick, (2) 1 in. thick. Installation cost equals 100 to 125 per cent of material cost.

Electrical Auxiliaries

The total installed cost of electrical substations and feeders may be estimated from Table 22. The purchased prices of motors are shown in Figs. 73 to 75; installation expense may be estimated at 100 per cent of the motor price.[1, 16, 18, 22, 36, 37]

Table 22. Installed Cost of Electrical Auxiliaries

Auxiliary	*Cost*
Substations and switch gear	$30/kva
Overhead feeders	5/ft
Underground feeders	10/ft

The complete installed cost of substations, feeders, and wiring may be estimated as being equivalent to 10 to 15 per cent of the purchased-equipment value.

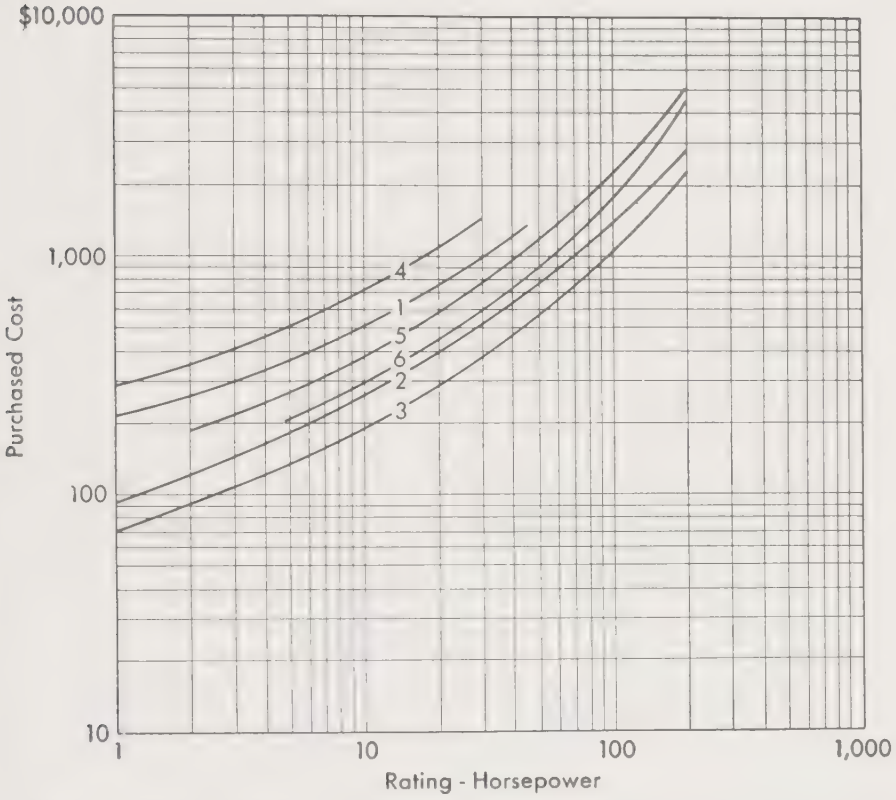


Fig. 73. Electric motors. *Alternating current, open:* (1) 600 rpm, (2) 1,200 rpm, (3) 1,800 rpm. *Alternating current, enclosed:* (4) 600 rpm, (5) 1,200 rpm, (6) 1,800 rpm.

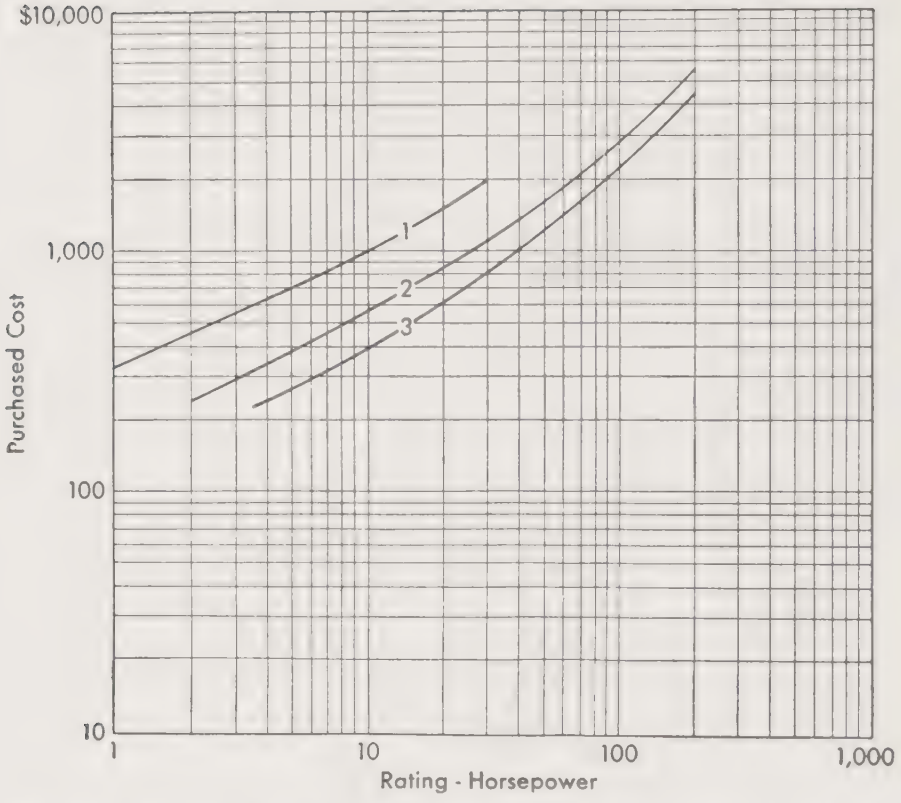


Fig. 74. Electric motors. *Alternating current, explosion-proof:* (1) 600 rpm, (2) 1,200 rpm, (3) 1,800 rpm.

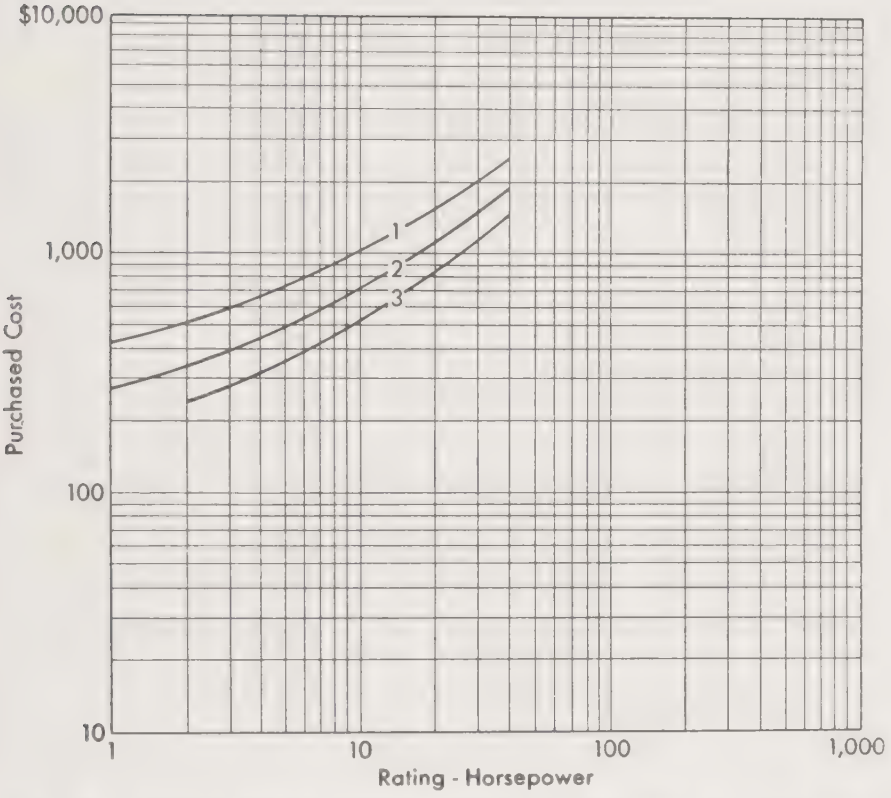


Fig. 75. Electric motors. *Direct current:* (1) 600 rpm, (2) 1,200 rpm, (3) 1,800 rpm.

Buildings

The most practical method of calculating the approximate total erected cost of buildings for chemical processing, without resorting to a detailed construction estimate, is based on the cost per square foot of floor area. Tables 23 to 26 list the erected unit costs of buildings and building components and the installed cost of services.[6, 7, 14, 18, 22, 23, 25, 37]

Table 23. Total Erected Cost of Buildings

Type of building	*Cost per sq ft of floor area*
Laboratory:	
Steel frame, brick and concrete walls; concrete floors and roof; heating, lighting, plumbing, sprinklers	$20
Laboratory equipment	22
Office:	
Steel frame, brick and concrete walls; concrete floors and roof; heating, lighting, plumbing, sprinklers	16
Office furniture	4
Warehouse, 1 story:	
Steel frame, brick and concrete walls; concrete floors and roof; heating, lighting, sprinklers	8
Steel frame, walls, and roof; concrete floor; lighting, sprinklers	4
Manufacturing, 15-ft floor clearance:	
Steel frame, brick and concrete walls; concrete floors and roof; heating, lighting, plumbing, sprinklers, elevators.	20
Steel frame, walls, and roof; concrete floors; lighting, plumbing, sprinklers	14
Steel frame and roof, concrete floors, open sides; lighting, sprinklers	9

Table 24. Total Erected Cost of Foundations and Structures

Type of foundation or structure	*Cost*
Excavation	$ 2/cu yd
Reinforced-concrete foundations	30/cu yd
Piling	100/pile
Structural steel	275/ton

Table 25. Total Erected Cost of Floors, Walls, and Roofs

	Cost per sq ft
Floors:	
Steel grating	$1.50
Reinforced ground-floor concrete	0.75
Reinforced concrete	1.40
Asphalt tile	0.40
Rubber tile	0.60
Walls:	
Brick	3.00
Cinder block	1.30
Poured concrete	1.50
Corrugated steel	0.70
Asbestos	0.60
Hollow tile	1.50
Glass block	3.00
Steel sash and glass	1.50
Roofs:	
Reinforced concrete	1.20
Corrugated steel	0.70
Asbestos	0.60

Table 26. Total Installed Cost of Building Services

Service	*Cost per sq ft of floor area*
Electrical lighting, warehouse	$0.50
Electrical lighting, processing building	1.00
Heating (excluding boiler)	1.00
Air conditioning	4.00
Sprinklers	0.50

The total erection cost of buildings, both for indoor and outdoor plant construction, may be estimated as equal to a percentage of the purchased-equipment value.

Table 27. Total Erected Building Cost

(Equivalent to percentages of purchased-equipment cost)

Equipment cost	Outdoor construction, %	Indoor construction, %
Less than $250,000.....	50	80
$250,000–$1,000,000...	40	65
More than $1,000,000..	30	50

Land and Yard Improvements

The value of land is a highly fluctuating item. It will vary extensively with so many factors that it should be checked for each location. In the absence of more exact values, the listing provided in Table 28 may be used for gross approximations of the cost of land. Table 29 may be employed to estimate the various costs of yard improvements.[6, 22, 25, 33]

The cost of yard improvements may be calculated as an

Table 28. Cost of Land

Type of land	*Purchased cost per acre*
Undeveloped land, rural area.....	$ 300
Undeveloped land, semi-industrialized area.....	1,000
Improved land, industrialized area.....	5,000

Table 29. Cost of Yard Improvements

Improvement	*Total cost*
Railroad siding.....	$12/linear ft
Concrete sidewalk.....	3/sq yd
Asphalt pavement.....	2.75/sq yd
Chain-link fence, 6 ft high.....	2.75/linear ft

amount equivalent to 10 to 15 per cent of the purchased-equipment price.

Utilities

Service facilities include steam, electricity, water, and refrigeration. Table 30, listing various utility costs per unit of capacity, may be used to approximate total installed costs. Figures 76 to 81 show the total installed costs of services as functions of capacities. The purchased cost of other types of equipment, which at times may be considered as utilities, will be found in the process-equipment section of this book (Chap. 2).[1, 12, 13, 18, 29, 30, 35, 37]

Table 30. Total Installed Costs of Utilities

Type of utility	*Total installed cost*
Steam	$ 5/lb/hr
Electricity	200/kva
Refrigeration	500/ton
Well water	0.40 gph
Filtered water	1.25/gph
Softened water	2.50/gph
Cooling towers	0.50/gph
Sewage disposal	2.50/gph
Manufactured gas	4/cfh
Compressed air	40/cfm

The total installed cost of plant utilities may be determined as amounts equivalent to percentages of the purchased-equipment cost.

Table 31. Total Installed Utility Cost

(Equivalent to percentages of purchased-equipment cost)

Type of services	*Installed cost, %*
Minimum additional services	25
Average services	40
Complete new services	75

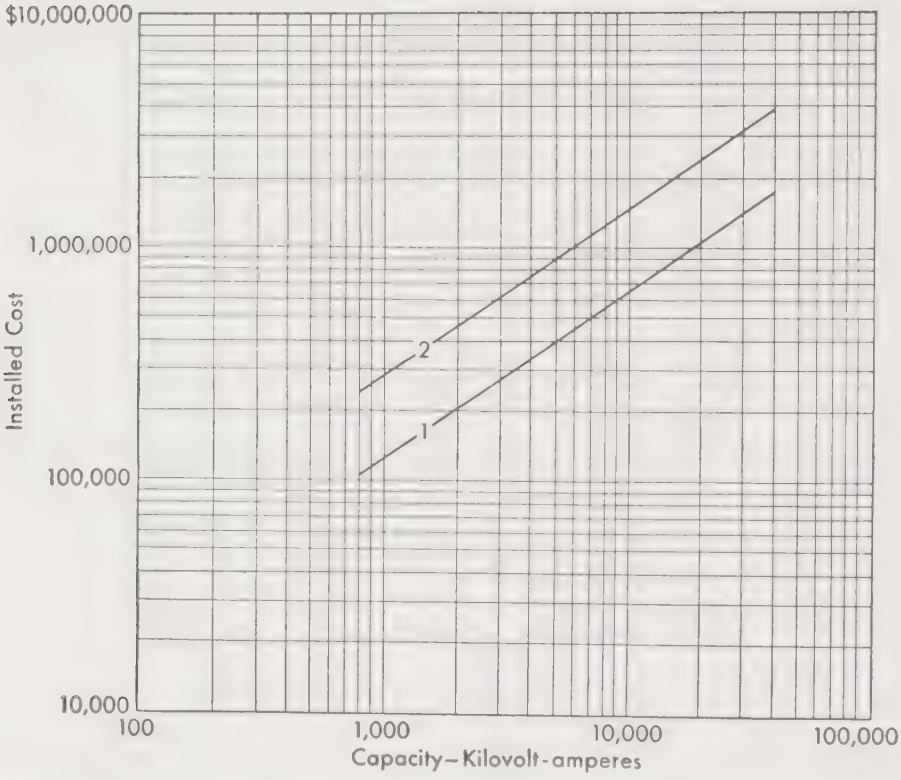


Fig. 76. Electric generators. (1) Turbogenerator unit, (2) unit and steam boiler.

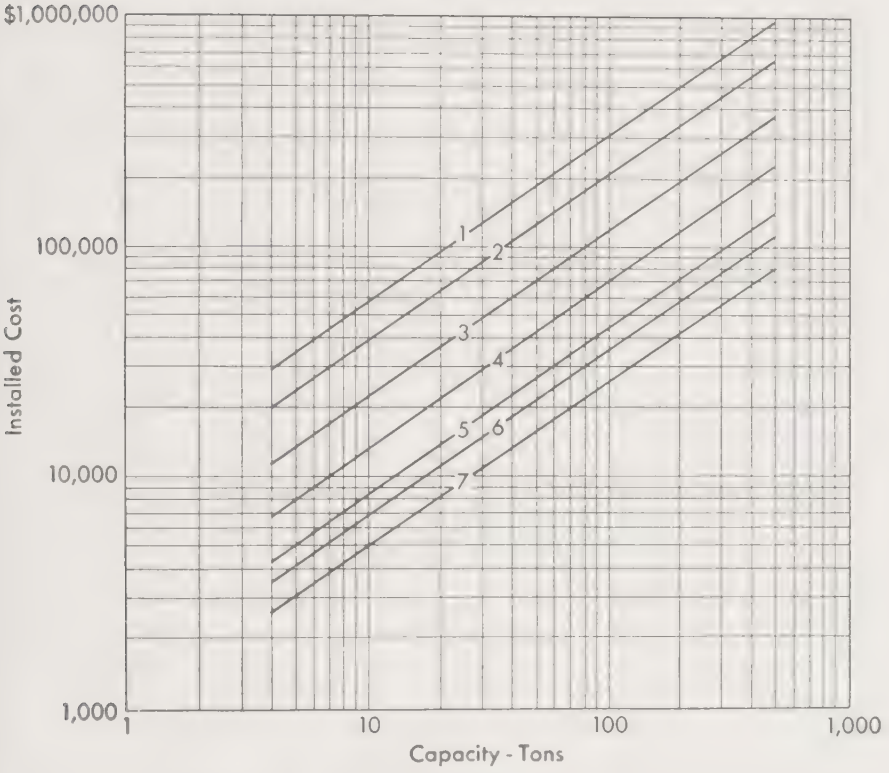


Fig. 77. Refrigeration. *Mechanical:* (1) −80°F, (2) −60°F, (3) −40°F, (4) −20°F, (5) 0°F, (6) +20°F, (7) +40°F.

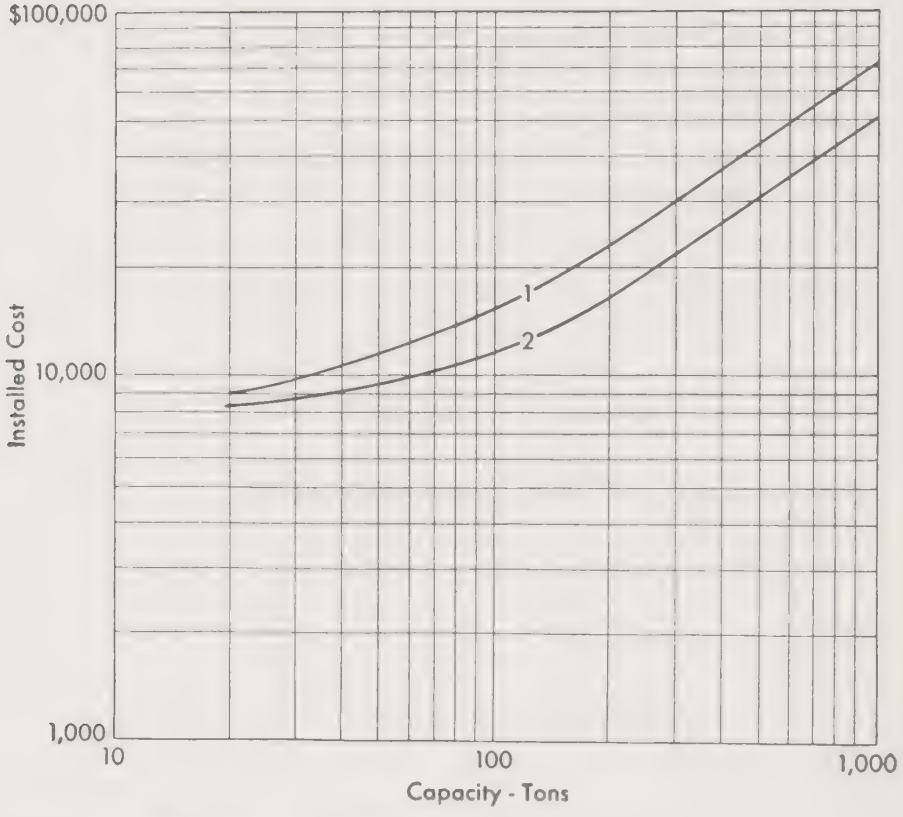


Fig. 78. Refrigeration. *Steam jet:* (1) 50°F, (2) 70°F.

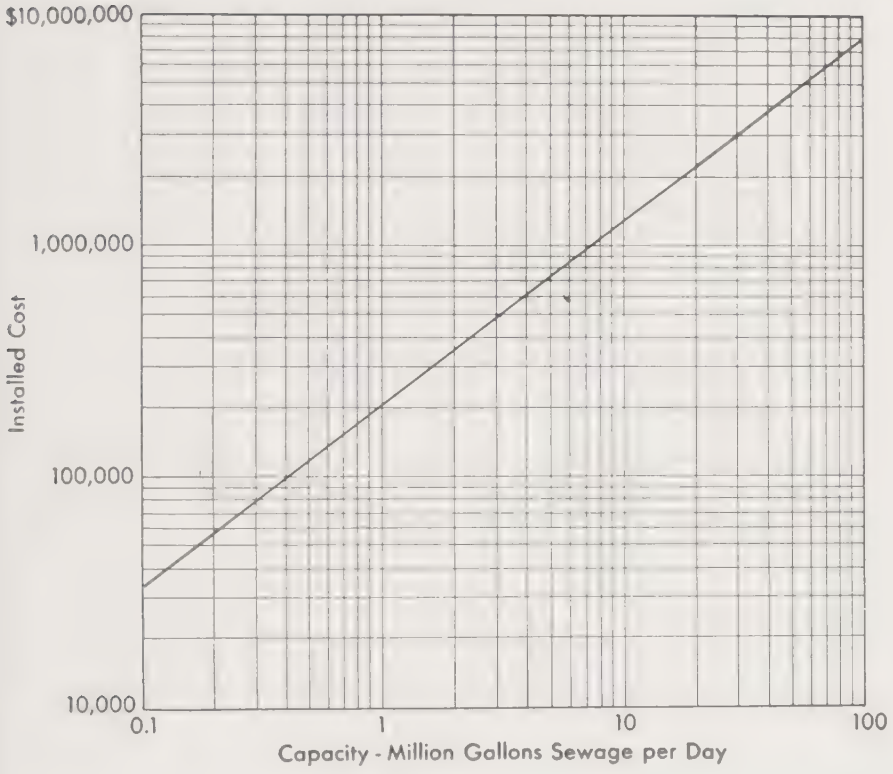


Fig. 79. Sewage disposal. Solids removal and stabilization.

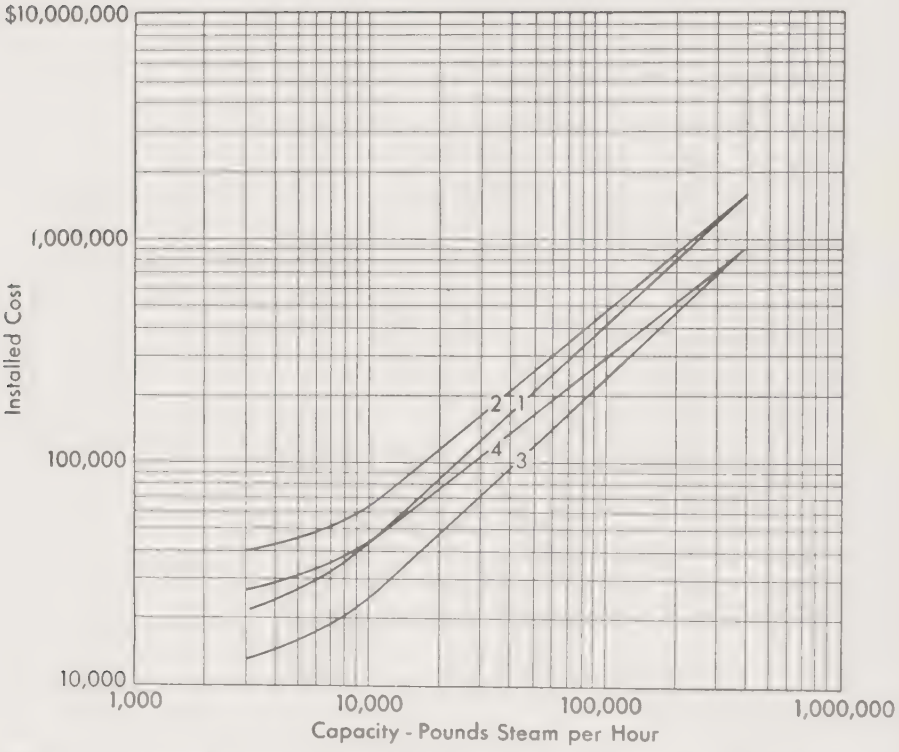


Fig. 80. Steam boilers. *Coal:* (1) 200 psi, (2) 1,000 psi. *Oil or gas:* (3) 200 psi, (4) 1,000 psi.

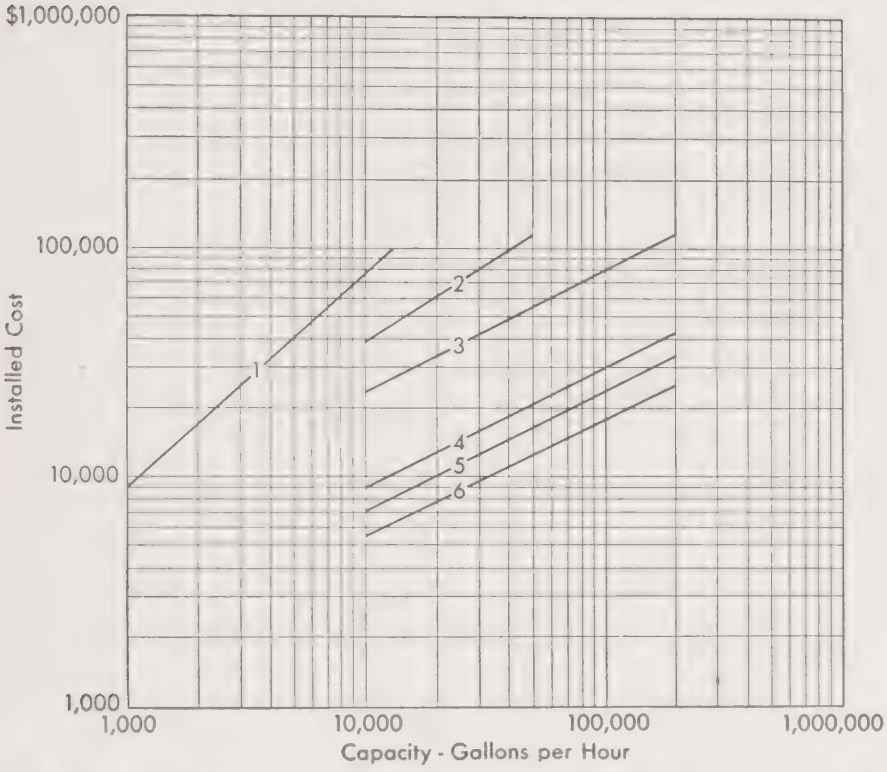


Fig. 81. Water systems. (1) Demineralized, (2) softening treatment, (3) filtering treatment, (4) cooling towers, (5) well, (6) pumping station.

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4. MANUFACTURING COST

THE sum of all the direct, indirect, and fixed expenses incurred as a result of the actual manufacture of a product is called the manufacturing cost. Table 32 is an outline of its various components.

Table 32. Manufacturing-cost Estimate

Raw materials	$	
Labor		
Supervision		
Maintenance		
Plant supplies		
Royalties and patents		
Utilities		
Direct manufacturing cost		$
Payroll overhead	$	
Laboratory		
Plant overhead		
Packaging		
Shipping		
Indirect manufacturing cost		$
Depreciation	$	
Property taxes		
Insurance		
Fixed manufacturing cost		$
Manufacturing cost		$

Production costs are generally expressed in terms of cost per unit of output. Inasmuch as many of the articles of manufacturing expense are calculated on the basis of occurring over given intervals of time, the production rate must be known to determine the unit cost.[1–5, 11, 12, 14–16, 18, 22, 23, 36, 38, 42]

TYPES OF PROCESS CLASSIFICATION

Many chemical process operations involve the manufacture of more than one product. Therefore, consideration must be given to the correct allocation of production expense. In general a process will fit into one or more of the following classifications: [22, 36]

1. With the manufacture of a single product, the entire cost is charged to the one material.
2. When two or more primary materials are manufactured at the same time by the same process, the cost of operation may be divided between the products on the basis either of quantity produced or of relative value.
3. If a by-product results from the manufacture of a primary product, the value of the by-product minus the expense of additional processing should be credited against the cost of the primary material.

DIRECT COST

The direct manufacturing costs are those expenses which are incurred specifically in the manufacture of a product.

Raw Materials

Raw-materials expense may be subdivided into two types: first, the purchased cost plus delivery expense of all materials consumed in product manufacture; and, second, the amortized costs of catalytic materials over their useful lives. Considera-

tion should be given to the quantity and form of shipment, since these factors will influence the purchase price. Chemical price quotations should preferably be obtained from suppliers. In their absence, published prices such as those available in *Chemical and Engineering News* and the *Oil, Paint and Drug Reporter* may be employed. Table 33 lists quotations on various chemicals.

Table 33. Prices of Chemicals *

Chemical	*Price*
Acetaldehyde, 99%, tanks, delivered	$ 0.10
Acetanilide, powd., tech., bbl, c.l., delivered	0.29
Acetic anhydride, tanks and c.l., delivered	0.14
Acetoacetanilide, small quantities	0.75
Acetoacet-*o*-chloranilide, 250-lb bbl, delivered	1.27
Acetone, tanks, delivered	0.08
Acetonitrile, tanks, works	0.43
Acetophenone, tech., drums, l.c.l., works	0.75
Acid:	
Abietic, cryst., drums, c.l., works	0.06
Acetic, glacial, tech., tanks	0.10
Acetylsalicylic, USP, drums	0.55
Adipic, c.l.	0.37
Alkylnaphthalene sulfonic, drums, works	0.35
p-Aminobenzoic, tech., drums, works	1.74
p-Aminosalicylic, drums, delivered	4.25
Anisic, drums, 10,000-lb lots	1.59
Anthranilic, tech., bbl, works	1.21
Arsenic (anhydride), powd., tech., drums	0.50
Arsenous, powd., USP, drums	0.48
Benzilic, drums	1.84
Benzoic, tech., drums	0.44
USP, drums	0.54
o-Benzoylbenzoic, c.l.	0.71
Boric, 99½%, cryst., tech., bags, c.l., works, per ton	124.25
Gran., bulk, c.l., works, per ton	94.25
Butyric, 99%, tanks	0.32

* The prices in this table are the lowest reported large-quantity prices. All values are in dollars per pound unless otherwise specified.

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Capric, 90%, drums	$ 0.24
Caproic, c.l., works	0.89
Caprylic, 90%, tanks, c.l.	0.32
Chloroacetic, mono-, tech., l.c.l., works	0.20
o-Chlorobenzoic, bbl	1.15
p-Chlorobenzoic, drums	1.64
Chlorosulfonic, tanks, per cwt	4.15
Chromic, 99½%, drums, l.c.l., works	0.27
Cinnamic, tech., small quantities	1.70
Citric, anhydrous, gran., USP, drums, c.l.	0.28
Hydrous, gran., drums, l.c.l.	0.27
Cresylic, coal tar, low b.p., tanks, works, per gal	0.95
Petroleum, drums, c.l., works, per gal	0.71
Crotonic, l.c.l., drums, works	0.55
Cyanoacetic, drums, works	0.90
Dichlorobenzoic, small quantities	1.09
2-4-Dichlorobenzoic, small quantities	1.36
Formic, 85%, l.c.l.	0.15
Fumaric, tech., delivered	0.27
d-Gluconic, 50%, tech., drums, works	0.15
l-Glutamic, 99%, pharmaceutical, works	2.45
Glycerophosphoric, 35%	2.55
Heptanoic, 95%, tech., works	1.80
Hydriodic, 45–47%, small quantities, works	2.67
Hydrobromic, gas, tech. and med., truckloads	0.34
Hydrochloric, 18°, tanks, works, per 100 lb	1.40
20°, carboys, tanks, works, per 100 lb	1.75
Hydrogen chloride, anhydrous, truckloads, works	0.45
Hydrocyanic, steel cylinders, works	0.75
Hydrofluoric, anhydrous, tanks, works	0.21
60%, drums	0.17
30%, drums, works	0.10
Hydrofluosilicic, 30%, bbl, works	0.10
Hydroxyacetic, 70%, tech., tanks	0.09
Lactic, 50%, edible, tanks, works	0.17
85%, liquid, USP, carboys	0.85
44%, tech., tanks	0.10

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Lauric, 90–95%, tanks, works	$ 0.39
Maleic, drums, delivered	0.37
Methacrylic, 98%, glacial, c.l.	0.54
90%	0.84
Methylenedisalicylic, bbl	0.75
Myristic, tanks and c.l.	0.27
Naphthenic, tanks, works	0.12
Nitric, 38°, tech., carboys, c.l., works, per 100 lb	6.00
p-Nitrobenzoic, tech., drums	0.73
Oleic, undistilled, tanks and c.l., works	0.15
Oxalic, bbl, l.c.l., works	0.16
Palmitic, tanks and c.l., delivered	0.13
Perchloric, 70–72%, carboys, works	0.61
60%, carboys, works	0.58
p-Phenolsulfonic, 65 and 70% soln., drums, l.c.l.	0.14
Phenylacetic, tech., drums	0.75
Phosphoric, 85%, NF, tanks, per 100 lb	6.15
Picric, NF, tech., bbl	0.32
Polymethacrylic, works	1.25
Propionic, tanks, works	0.20
Pyroligneous, drums, l.c.l., works, per gal	0.36
Salicylic, crude, drums	0.36
Cryst. bbl	0.48
Powd., USP, bbl	0.48
Tech., l.c.l.	0.37
Sebacic, purif., drums, l.c.l., works	0.64
Sorbic, drums, works	2.40
Stearic, single-pressed, tanks and c.l., delivered	0.11
Succinic, cryst., purif., drums, works	0.63
Sulfanilic, tech., l.c.l., works	0.19
Sulfuric, 98, 99, 100%, tanks, works, per ton	23.50
66° Bé, tanks, works, per ton	22.35
60° Bé, tanks, works, per ton	18.60
Oleum, 20°, tanks, works, per ton	25.00
Sulfurous, 6%, carboys	0.10
Tannic, tech., small quantities	0.99
Tartaric, drums	0.40

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Thioglycolic, carboys, works	$ 1.60
p-Toluenesulfonic, l.c.l.	0.18
Acrolein, tech., works, l.c.l.	0.47
Acrylonitrile, tanks, works	0.31
Albumin, egg, cryst., tech., bbl	0.85
Albumin, blood, light, drums, l.c.l.	0.65
Alcohol:	
Allyl, tanks	0.30
Amyl, ex–fused-oil, tech., tanks and c.l.	0.16
Ex-pentane, tanks	0.15
Benzyl, tech., drums	0.47
n-Butyl, synthetic, tanks, cars	0.13
Capryl, 95%, tanks, works	0.18
85%, tanks and c.l.	0.16
Cetyl, small quantities	0.53
n-Decyl (1-decanol), tech., tanks, delivered	0.32
Decyl (oxo), tanks and c.l.	0.21
Denatured, tanks, delivered, per gal	0.42
Diethylcarbinol, l.c.l.	0.46
Ethyl, absolute, tax-paid, tanks, delivered, per gal	22.00
190-proof, pure, tax-free, tanks, delivered, per gal	0.40
190-proof, tax-paid, tanks, delivered, per gal	20.35
2-Ethylbutyl, tanks, works	0.28
2-Ethylhexyl, tanks, c.l., delivered	0.21
Furfuryl, tanks	0.18
3-Heptanol, tech., tanks	0.23
Heptyl, 90% min., tech., drums	1.80
Isobutyl, refined, tanks, delivered	0.12
Isooctyl, tanks, delivered	0.21
Isopropyl, 99%, refined, tanks, delivered, per gal	0.39
91%, tanks, delivered, per gal	0.35
Lauryl, tech., tanks, delivered	0.40
Methyl, synthetic, tanks, works, per gal	0.27
Natural, tanks, per gal	0.70
Methylamyl, tanks, c.l., delivered	0.13
Nonyl, tanks, works	0.27
Oleyl, tanks	0.51

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
2-Phenylethyl, small quantities	$ 1.45
Polyvinyl, fully hydrolyzed, ton lots	0.72
n-Propyl, tanks and c.l.	0.10
Stearyl, indust., tanks	0.38
USP, drums	0.50
Tetrahydrofurfuryl, tank cars	0.43
Indust., tank cars	0.29
Tridecyl, tanks and c.l.	0.27
Allyl bromide, small quantities	1.30
Caproate, small quantities	3.45
Chloride, tanks, delivered	0.15
Aloin, USP, bbl	3.50
Alum:	
Ammonium, burnt, USP, bbl	0.20
Gran., drums, works, per 100 lb	3.80
Hydrous	0.09
Potassium, gran., bbl, works, per 100 lb	4.05
Hydrous	0.10
Lump, drums, works, per 100 lb	4.80
Powd., drums, works, per 100 lb	10.25
Potassium-chrome, bbl	0.17
Sodium, bbl, c.l., works, per 100 lb	4.60
Alumina, calcined, c.l., bags, F.O.B., works	0.04
Hydrated, chem. ceramic, l.c.l. bags, F.O.B. works	0.03
Aluminum, 99%, metal, pig	0.20
Acetate, 24% soln., drums, works	0.14
20% normal soln., l.c.l., works	0.11
Chloride, anhydrous, comm., drums	0.15
NF, gran., 1,000-lb lots	0.28
Formate, 22.4% basic soln., drums, works	0.09
Hydroxide, USP, gel, powd., drums	0.79
Naphthenate, liquid, 1.7% Al	0.30
Resinate, 2.1%, drums	0.29
Stearate, tech., dibasic, l.c.l.	0.33
Sulfate, gran., ground, comm., tech., c.l., works, per 100 lb	1.85
p-Amino acetanilid, l.c.l.	1.45

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
p-Aminobiphenyl, tanks and c.l.	$ 0.63
2-Aminoethylamino-1-ethanol, tanks	0.45
Aminoguanidine bicarbonate, drums, works	3.00
2-Amino-2-methyl-1,3-propanediol, drums, works	1.35
2-Amino-2-methyl-1-propanol, drums, works	0.60
m-Aminophenol, drums, delivered	2.05
p-Aminophenol, drums, works	0.97
Aminophylline, USP, drums	3.55
Aminopyrine, USP, 1,000 lb	4.50
Ammonia, anhydrous, refrig., tanks, works, per ton	87.50
Fertilizer, comm. tanks, works, per ton	85.00
Industrial, pure, cyl.	0.18
Ammoniacal liquor, anhydrous basis, tanks, works, per ton	96.00
Ammonium acetate, cryst., purif., drums	0.38
Benzoate, USP, 4,000-lb lots, per keg	0.80
Bicarbonate, drums, c.l., works	0.06
Bifluoride, purif., flake, small quantities	0.34
Bromide, gran. NF, l.c.l.	0.37
Carbonate, USP, drums	0.23
Chloride, white, gran., tech., c.l., works	0.05
Citrate, dibasic, bbl	0.75
Dichromate, purif., gran., drums	0.62
Hypophosphite, NF, drums	2.40
Molybdate, cryst., CP, drums	1.27
Nitrate, fertilizer bags, works, per ton	68.00
Oleate, 75%, drums, works	0.55
Oxalate, tech., drums	0.26
Pentaborate, gran., bbl, c.l., works, per ton	227.00
Perchlorate, kegs	0.50
Persulfate, tech., drums	0.18
Phosphate, dibasic, NF, small quantities	0.45
Quaternary salts (*n*-alkyltrimethylammonium chlorides), 33% active, cocoa, drums, c.l., works	0.33
Dilauryl dimethylammonium chloride (from reduced coconut oil), 75% active, c.l.	0.53

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Distearyldimethylammonium chloride (includes palmityl from reduced tallow), 75% active	$ 0.37
Lauryl, 33% active, drums, c.l., works	0.36
Palmityl, 50% active, drums, c.l., works	0.39
Soya, 33% active, drums, c.l., works	0.26
Stearyl, 50% active, drums, c.l., works	0.37
Salicylate, NF, 200-lb fiber drums	1.62
Silicofluoride, bbl, works	0.11
Stearate, 22–25%, paste, drums, l.c.l.	0.10
Sulfate, bulk, F.O.B. cars, per ton	42.00
Sulfide, liquid, 40–50% drums, c.l., works	0.12
Sulfite, purif., drums, small quantities	0.46
Thiocyanate, tech., drums, c.l.	0.20
Thioglycolate, 100%, carboys	1.60
Thiosulfate, cryst., drums	0.65
Amyl acetate, F.O.B., tanks	0.15
n-Butyrate, drums	0.95
Cinnamaldehyde, drums	1.05
Phenol, *p*-tert, tanks and c.l., works	0.23
Salicylate, small quantities	0.75
Valerate, small quantities	1.95
Aniline, tanks, l.c.l.	0.20
Salt, drums, l.c.l., works	0.33
Anthracene, 90–95%, bbl, ton lots and less	0.95
Anthraquinone, 99.5%, bbl	0.88
Antimony, metal	0.28
Chloride, soln., carboys	0.33
Oxide, ceramic or pigments, bags, l.c.l., delivered	0.29
Sulfide, 62–70%, works	0.27
Trichloride, anhydrous, solid, l.c.l., works	0.38
Arsenic, metal, lump, drums	0.60
Trioxide (white arsenic), 99%, powd., bbl, c.l., delivered	0.05
Barium bromide, 100-lb drums, works	0.49
Carbonate, precip., bags, works, per ton	92.50
Chlorate, kegs, works	0.34

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Chloride, tech., l.c.l., works, per 100 lb	$ 6.00
Chromate, bag	0.30
Dioxide (peroxide), drums, c.l., works	0.14
Hydrate, cryst., bags	0.09
Hydroxide, pentaanhydrous, bags, l.c.l., per 100 lb.	10.90
Nitrate, fines, bbl, c.l.	0.12
Oxide, ground, drums, works	0.12
Peroxide, drums	0.16
Potassium chromate pigment, l.c.l., delivered	0.30
Stearate, l.c.l.	0.37
Sulfate, natural (barytes), water gr., floated, bleached, c.l., per ton	41.35
Bauxite, bulk, mines, per ton	9.50
Bentonite, bags, works, per ton	14.00
Benzaldehyde, tech., drums	0.44
Benzene, pure, nitration, tanks, works, per gal	0.42
Benzil, 1,000-lb lots	1.85
Benzocaine, USP, drums	3.48
Benzoin, 1,000-lb containers	0.94
Benzophenone, small quantities	1.50
Benzotrichloride, carboys	0.18
Benzoyl chloride, drums and carboys, l.c.l.	0.21
Benzyl acetate, drums	0.64
Benzoate, small quantities	0.62
Butyrate, small quantities	1.80
Chloride, tech., drums, l.c.l., works	0.20
Cyanide, drums, works	0.70
Propionate, small quantities	1.65
Salicylate, small quantities	1.85
Benzylidene chloride, tech.	0.22
Benzyltrimethylammonium chloride, tech., carboys	0.22
p-Benzylphenol, drums	5.35
Bisbutoxyethyl sebacate, drums, c.l., works	0.55
Bis-2-ethylbutyl phthalate, tanks and c.l., delivered	0.34
Bis-2-ethylhexyl phthalate, tanks and c.l., delivered	0.34
Adipate, l.c.l.	0.46
Bis-2-methoxyethyl phthalate, tanks and c.l., delivered	0.42

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Bismuth chloride, small quantities	$ 5.11
Citrate (ammonium), USP, small quantities	4.22
Nitrate, cryst., drums	2.08
Oxide, anhydrous, drums	4.42
Black, acetylene, c.l. lots, F.O.B., bags	0.17
Bone, l.c.l.	0.15
Carbon, channel, rubber, bulk, hop car, works	0.07
Furnace, fast-extruding bags, c.l., works	0.06
Semireinforcing, bags, c.l., works	0.04
Iron oxide, synthetic, bags, l.c.l.	0.12
Lamp, thermal, fine, bags, c.l.	0.05
Bleaching powder, drums, c.l., works, per 100 lb	5.02
Blue, alkali, dry, bbl, delivered	2.10
Cobalt, genuine, bbl, delivered	4.90
Iron, lots, bags	0.48
Prussian, bbl, delivered	0.48
Phthalocyanine, standard, drums, lots	3.45
Ultramarine, cobalt-type, dry or pulp, delivered	0.30
Borax, anhydrous, bulk, works, per ton	70.00
Tech., gran., bulk, works, per ton	35.75
Bordeaux mix, bags, c.l., works	0.18
Bromine, tanks	0.19
n-Bromoacetamide, drums, works	4.70
3-Bromo-5,5-dimethylhydantoin, small quantities	7.50
Bromoform	1.65
2-Bromopyridine, l.c.l.	17.00
n-Bromosuccinimide, 44.5% bromine, drums, 1,000-lb lots	3.40
Bronze powder, gold, litho, drums, works	0.75
Brown iron oxide, per 100 lb	12.00
Metallic, per 100 lb	4.00
Sienna, burnt, bags, l.c.l., works, per 100 lb	4.25
Butadiene, tanks and cyl., works	0.12
Butane, industrial, group 3 tanks, per gal	0.13
1,3-Butanediol, tanks	0.14
1,4-Butanediol, l.c.l., works	0.40
2,3-Butanediol, tanks	0.14

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
2-Butoxyethanol (butyl Cellosolve), tanks, works	$ 0.18
n-Butyl acetate, synthetic, tanks, drums, c.l., delivered	0.13
sec-, tanks, delivered	0.10
Benzyl phthalate, tanks	0.27
Benzyl sebacate, tanks, works	0.56
Lactate, tanks and c.l.	0.33
Methacrylate, l.c.l., works	0.69
Oleate, refined, drums, l.c.l.	0.26
Peroxide, ditert, drums, l.c.l.	1.96
Phenylacetate, drums	4.50
Stearate, tech., drums, l.c.l.	0.21
Butylamine, mono-, tanks	0.53
sec-Butylbenzene, drums, l.c.l., works	0.06
p-tert-Butylphenol, bags, l.c.l., works	0.27
Butyraldehyde, tanks, delivered	0.19
Cadmium, metal, sticks, anodes	1.70
Bromide, cryst., small quantities	2.50
Chloride, purif., cryst., drums	2.68
Iodide, drums, small quantities	6.75
Oxide, c.l., works	1.75
Stearate, l.c.l.	1.30
Sulfate, tech., drums	2.00
Caffeine, hydrous, USP, drums	3.15
Calamine, powd., USP, drums	0.34
Calcium acetate, pure, drums	0.30
p-Aminosalicylate, works	7.00
Arsenate, drums, l.c.l., works	0.09
Benzoate, drums	0.85
Bromide, NF, powd., drums	0.90
Carbide, quarter, nut, egg, lump, c.l., delivered 100-lb drums, per 100 lb	6.59
Carbonate, precip., USP, bags	0.06
Chloride, anhydrous, purif., gran	0.27
77–80%, flake, bags, c.l., works, per ton	27.00
73–75%, solid, drums, c.l., works, per ton	25.50
Chromate, bags	0.29

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Cyanide, drums, delivered, per ton	$160.00
Formate, 80-lb bags, l.c.l., works	0.04
Gluconate, powd., USP, drums	0.60
Glycerophosphate, NF, drums	2.30
Hypochlorite (fused alkali), drums, delivered, per 100 lb	28.65
Hypophosphite, NF, drums	0.90
Lactate, USP, drums, l.c.l.	0.40
Mandelate, USP, drums, works	2.10
Molybdate, lb-contained-Mo	1.05
Naphthenate, 4% liquid, l.c.l.	0.26
Nitrate, tech., cryst.	0.13
Peroxide, drums, works	0.80
Phenolsulfonate (sulfocarbolate), drums	0.70
Phosphate, dibasic, feed, bags, c.l., works, per ton	74.00
Resinate, precip., 5.23% Ca, drums, works	0.29
Salicylate, drums, l.c.l.	1.93
Silicate, hydrate, bags, c.l., works	0.06
Stearate, tech., l.c.l.	0.35
Sulfate, anhydrous, bags, c.l., works, per ton	45.00
Sulfite, drums	0.18
Thiocyanate, purif., liquid, 55–60%, carboys	0.64
Camphene, tanks, works	0.08
Camphor, powd., tech., 100-lb drums, bbl	0.49
Capryl benzyl sebacate, tanks, works	0.89
Carbazole, 95–97%, steel drums	0.95
Carbinol, *n*-butyl-, tanks and c.l.	0.40
Diisobutyl-, tanks	0.24
Methylisobutyl-, tanks	0.13
Carbon, activated, decolorizing, "C" type, c.l., works	0.08
Bisulfide, tanks, per 100 lb	5.25
Dioxide, cyl.	0.08
Tetrachloride, tech., tanks	0.08
Casein, domestic, standard	0.27
Cathechol, CP, drums, works	2.17
a-Cellulose, bags, c.l., works	0.04

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Cellulose acetate, cartons, works	$ 0.37
Butyrate, flake, powd., works	0.54
Molding composition, c.l.	0.64
Triacetate, flake, cartons, works	0.52
Cerium hydrate, drums, works	1.44
Chalk, bags, c.l., works, per ton	40.00
Charcoal, hardwood, gran., bags, c.l., works, per ton	77.00
Chloral hydrate, tech., drums, l.c.l., works	0.23
Chlordan, agricultural, drums, l.c.l.	0.65
Chlorine, tanks, per 100 lb	3.00
Liquid, cyl.	0.09
m-Chloroaniline, tanks, c.l., works	0.73
o-Chloroaniline, drums, l.c.l.	0.70
p-Chloroaniline, drums	0.75
o-Chloro-*p*-anisidine, drums	1.36
o-Chlorobenzaldehyde, drums	1.20
Chlorobenzene, mono-, tanks	0.10
o-Chlorobenzotrichloride, carboys	0.60
p-Chlorobenzotrichloride, carboys, l.c.l.	0.38
o-Chlorobenzoyl chloride, carboys	0.91
p-Chlorobenzoyl chloride, carboys	0.85
o-Chlorobenzyl chloride, carboys, 2,000-lb lots and over	0.70
p-Chlorobenzyl chloride	0.80
Chlorobutanol, anhydrous, USP	1.90
Hydrous	1.65
Chloroform, tech., tanks and trucks, works	0.17
o-Chloro-*p*-nitroaniline, drums	0.86
p-Chloro-*o*-nitroaniline	0.73
o-Chlorophenol, drums	0.34
p-Chlorophenol, drums, l.c.l.	0.34
Chloropicrin, comm., cyl.	0.95
2-Chloropyridine	17.50
n-Chlorosuccinimide, 26.2% drums	3.15
Chlorotoluene, mono-, drums, l.c.l., works	0.10
o-Chlorotoluene	0.39
p-Chlorotoluene, drums	0.45

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Choline chloride, 25%, bags or drums, 2,000 lb or more	$ 0.17
Chrome ore, cars, domestic, 48% 3 : 1 ratio, F.O.B., per gross ton	39.00
Chromium, metal, 97%	1.18
Acetate, 8½% soln., bbl	0.09
Fluoride, bbl, l.c.l., works	0.51
Phosphate	0.55
Cinchophen, NF, drums	3.50
Cinnamic aldehyde, NF IX, 400-lb lots	1.00
Coal tar, crude, tanks, works, per gal	0.16
Refined, tanks, works, per gal	0.17
Cobalt, metal, 97–98%, kegs	2.60
Acetate, 23¼% Co, bbl, delivered	1.37
Carbonate, powd., 46% Co, bags, works	2.28
Chloride, 24½% Co, kegs, works	1.27
Hydrate, 60¾% Co, bbl	2.90
Linoleate, 8½% Co, solid	0.75
Naphthenate, 6% Co, liquid, l.c.l.	0.47
Nitrate, tech., 20.4% cryst., drums	1.12
Octoate, 6%, l.c.l.	0.51
Oxide, 71%, ceramic, kegs, delivered	1.96
Resinate, 3%	0.29
Soyate, 8½% Co	0.73
Sulfate, 21% Co	0.95
Tallate, 6% Co, liquid, l.c.l.	0.43
Collodion, USP, l.c.l., delivered	0.27
Copper, metal, electrolytic	0.30
Acetate, drums, l.c.l.	0.40
Carbonate, 55%, bbl	0.26
Chloride, cryst., tech., bbl	0.27
Cyanide, drums	0.63
Hydroxide, drums, l.c.l., delivered	0.40
Linoleate	0.35
Naphthenate, 8% Cu, liquid, l.c.l.	0.22
Nitrate, cryst., tech.	0.30
Oleate, 8½% Cu, liquid, bbl	0.27
Oxide, black, bbl, works	0.45

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Oxychloride, drums, l.c.l., works	$ 0.40
Resinate, 8½% Cu, precip., drums	0.29
Stearate, bags, works	0.38
Sulfate, 99%, cryst., bags, c.l., works, per 100 lb	10.35
Corn sugar, bags, 60,000-lb min., per 100 lb	7.31
Coumarin, cryst., NF, small quantities	2.95
Creosote, NF, carbonate, carboys	3.30
Coal tar, crude, tank, works, per gal	0.22
Pinewood, tank, works, per gal	0.43
Cresol, tech., tanks, works	0.12
Mixed *m*- and *p*-, 5°, works, tanks, c.l.	0.13
m-Cresol, 70–75%, drums, works	0.50
o-Cresol, pure 30°, tanks and c.l.	0.16
p-Cresol, 98%, drums, works	0.50
Crotonaldehyde, 91% min., tanks and c.l., delivered	0.21
Cryolite, natural, insecticide, l.c.l., works, per 100 lb	15.25
Cuminic aldehyde	3.00
Cyanamide, 20% N, gran., 100-lb bags, works, per ton	55.00
Cyanide, chloride, mixt., 30% case hardener, 20,000-lb lots	0.09
Cyanoacetamide, drums	1.85
Cyanuric chloride, drums, works	1.35
Cyclohexane, tanks, per gal	0.55
Cyclohexanol, tech., tanks	0.37
Cyclohexanone, drums, c.l., works	0.28
Cyclohexyl butyrate, drums, works	2.00
Cyclohexylamine, drums, tanks and c.l., works	0.45
Cyclopentanol, drums, delivered	4.50
Cyclopentanone, drums	2.50
p-Cymene, drums, works, per gal	2.50
Decahydronaphthalene, drums, delivered	0.50
n-Decylacetamide, tech., 1- to 9-drum lots, works	1.25
Dextrin, corn, British, gum, bags, c.l., per 100 lb	8.95
Potato, domestic, bags	0.10
Dextrose, gran., CP, drums	0.14
Diacetyl, flavoring, 48-lb. lots	4.50

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Dianisidine, m.p. 137–138°, drums	$ 2.00
Diatomaceous earth, domestic, bags, c.l., per ton	52.00
Dibenzyl sebacate, drums, c.l., works	0.92
p-Dibromobenzene, bags	0.55
1,3-Dibromo-5,5-dimethylhydantoin, drums	3.30
Dibutyl maleate, drums, l.c.l., works	0.50
Phthalate, tanks and c.l., delivered	0.30
Sebacate, tech., drums, l.c.l., works	0.67
Tartrate, drums, works	0.71
Dibutylamine, tanks, delivered	0.53
Dicapryladipate, tanks, c.l., delivered	0.43
Phthalate, drums, l.c.l., delivered	0.32
Sebacate, tech., drums, c.l., works	0.62
Dichloroaniline, drums	0.83
Dichlorobenzaldehyde, 2-4 and 3-4 drums	1.36
o-Dichlorobenzene, tanks	0.10
p-Dichlorobenzene, drums, l.c.l., works	0.16
Dichloropentane, refined, tanks and truck lots, works	0.04
2,4-Dichlorophenol, tech., drums, c.l., works	0.31
Dicoumarol, drums, works, per 100 lb	24.00
Dicyandiamide, bags, works	0.15
Dicyclohexyl phthalate, l.c.l.	0.59
Dicyclohexylamine, tanks, c.l.	0.49
Dieldrin, flake, tech., drums, c.l.	1.80
Diethanolamine, tanks, delivered	0.24
Diethyl carbonate, tanks, works	0.45
Maleate, tanks	0.48
Malonate, drums, works	0.77
Oxalate, tanks and c.l.	0.40
Phthalate, tanks	0.25
Sulfate, tanks, works	0.17
Diethylamine, tanks, delivered	0.48
2-Diethylamino-1-ethanol, tanks	0.65
n,n-Diethylaniline, tech., tanks	0.50
Diethylene glycol, tanks and c.l., delivered	0.14
Diethyl ether, drums, c.l., works	0.46
Dimethyl ether, drums	1.10

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Monobutyl ether, tanks and c.l., works	$ 0.27
Monobutyl ether acetate, drums, c.l., works	0.30
Monoethyl ether, tanks and c.l., delivered	0.19
Monoethyl ether acetate, tanks and c.l., works	0.25
Monomethyl ether, tanks and c.l., delivered	0.18
Diethylenetriamine, tanks and c.l., delivered	0.41
Diglycol laurate, drums, l.c.l.	0.35
Stearate, bbl, c.l.	0.26
Dihexyl adipate, drums, c.l., delivered	0.44
Phthalate, drums, c.l., delivered	0.32
Sebacate, drums, l.c.l., works	0.64
Diisobutyl ketone, tanks and car lots, delivered	0.13
Diisobutylene, tanks	0.08
Diisoctyl adipate, c.l. and l.c.l., delivered	0.45
Phthalate, tanks and c.l., delivered	0.30
Sebacate, drums, l.c.l., works	0.64
Dioctylphthalate, tanks and c.l., delivered	0.32
p-Dimethoxybenzene, 500-lb lots	2.25
1,2-Dimethoxyethane, drums	0.90
n,*n*-Dimethylamine, tank cars, works	0.33
Dimethylaniline, tanks, l.c.l.	0.28
Dimethyl ether, cyl., c.l.	0.18
Dimethyl maleate, drums, l.c.l., works	0.60
Phthalate, tanks	0.27
Sebacate, tanks, works	1.25
Sulfate, drums, l.c.l., works	0.15
n,*n*-Dimethylamine, tank cars, works	0.33
Dimethylaniline, tanks, l.c.l.	0.28
Dimethylanthranilate, cans	5.75
n,*n*-Dimethylformamide, tanks and drums, works	0.33
2,4-Dinitroaniline, drums	0.68
m-Dinitrobenzene, bbl, delivered	0.20
2,4-Dinitrochlorobenzene, l.c.l.	0.17
2,4-Dinitrophenol, tech., bbl	0.37
2,4-Dinitrotoluene, oil, tech., drums, delivered	0.10
Dioctyl adipate, tanks and c.l.	0.44
Phthalate, tanks, delivered	0.30

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Sebacate, drums, l.c.l., works	$ 0.65
1,4-Dioxane, tanks	0.27
Dipentaerythritol, drums, 30,000-lb lots	0.32
Dipentene, destruct., dist., drums, c.l., per gal	0.40
Diphenyl, bbl, c.l., works	0.15
Diphenylamine, bbl, l.c.l.	0.28
Diphenylguanidine, drums, ton lots	0.48
Dipropylene glycol, tanks	0.14
Dipropylene glycol methyl ether, tanks and drums, c.l.	0.20
Di-tert-amyl phenol, works, tanks	0.28
Di-tert-butyl peroxide, drums, l.c.l.	1.96
Di-tert-butyl-*p*-cresol, l.c.l., delivered	0.81
Di-*o*-tolylguanidine, drums	0.57
Divinylbenzene, 20–25%, tank cars	0.19
n-Dodecylammonium acetate, tech	0.52
Epichlorohydrin, tanks	0.37
Ethanolamine, mono-, tanks and tank trucks, delivered	0.25
Ether:	
Bis-2-chloroisopropyl, l.c.l., delivered	0.13
Bis-2-chloroethyl, purif., tanks and c.l.	0.13
n-Butyl, tanks and c.l., works	0.30
Ethyl, USP, tanks, delivered	0.12
Purif. (for fat extraction), drums	0.41
Synthetic, tanks and c.l.	0.10
Isopropyl, refined, tanks and c.l.	0.05
Ethoxyethanol acetate, tanks and c.l., works	0.16
2-Ethoxyethanol (Cellosolve), tanks, delivered, East	0.18
Ethyl acetate, 99%, synthetic, tank cars, delivered	0.11
Acetoacetate, tanks, c.l., delivered	0.53
Acrylate, monomer, tanks	0.42
Anthranilate	6.00
Benzoate, drums	0.76
Bromide, tech., tanks and c.l.	0.38
Butyrate, drums, works	0.80
Carbamate, USP, drums	1.50
Chloride, tech., tanks, works	0.10

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Chloroformate, 40-lb carboys	$ 0.45
Cinnamate, cans, small quantities	3.15
Cyanoacetate, drums	1.20
b-Ethoxypropionate, drums, works	0.72
Formate, l.c.l., delivered	0.45
Lactate, drums, l.c.l., works	0.47
Mercaptan, purif., drums, works	0.70
Methacrylate, drums, works	0.51
Nitrite, concn., bottles	2.75
Oenanthate, drums	1.00
Oleate, drums, l.c.l., works	0.53
Oxalate, drums, l.c.l.	0.41
Phenylacetate, drums	1.30
Silicate, drums, l.c.l.	0.53
Ethylamine, mono-, 70% based on contained amine, tanks	0.31
Ethylaniline, mono-, tanks and c.l., works	0.50
Ethylbenzene, tanks and c.l.	0.18
Ethylcellulose, flake, 23,000-lb lots or more	0.69
Ethylene carbonate, l.c.l.	0.50
Chlorohydrin, anhydrous, tanks and c.l., works	0.20
Cyanohydrin, tanks, c.l., works	0.36
Dibromide, tanks, delivered	0.29
Oxide, cyl., tanks	0.15
Ethylene glycol, tanks	0.13
Dimethyl ether	0.90
Ethylenediamine, 85% (based on contained amine), tanks and c.l., delivered	0.44
n-Ethyl-α-naphthylamine, tech., drums	1.02
n-Ethyl-*o*-toluidine, tech., bbl	0.88
Fatty acid, animal, double dist., tanks, trucks, and c.l., delivered	0.12
Coconut, double dist., tanks, trucks, and c.l., delivered	0.23
Corn oil, double dist., tanks, trucks, and c.l., delivered	0.13
Cottonseed, double dist., drums, tanks, trucks, and c.l., delivered	0.13

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Palm, double dist., tanks, trucks, and c.l., delivered	$ 0.13
Soybean, double dist., drums, tanks, trucks, and c.l., delivered	0.15
Feldspar, glassmakers, bulk, works, per ton	11.75
Ferric acetate, soln., USP IX, carboys	0.16
Ammonium citrate, gran., drums	0.59
Oxalate	0.25
Chloride, cryst., tech., 450-lb drums, per 100 lb	5.25
Citrate, gran., drums	0.86
Glycerophosphate, powd., NF	4.75
Hypophosphite, drums	2.80
Naphthenate, 6% Fe, liquid, l.c.l.	0.24
Nitrate, cryst	0.74
Oxalate, tech., drums	0.85
Phosphate, insol.	0.33
Potassium oxalate, fine gran., drums	0.30
Pyrophosphate, solid, gran., NF VII, drums	0.78
Resinate, 6¾% Fe, precip., drums	0.27
Stearate, drums, c.l.	0.37
Sulfate, anhydrous, bags, l.c.l., works, per ton	31.75
Tallate, 6% Fe, l.c.l.	0.21
Ferrous chloride, drums, works	0.03
Sulfate, drums, works	0.10
Sulfide, tech., lump, drums	0.10
Fluorspar, 70% CaF_2 content, metallurgical, domestic mines, per net ton	43.00
Formaldehyde, methanol-free, tanks, works	0.03
Formamide, tanks	0.10
Fuller's earth, 30–60-mesh, F.O.B. Ga. or Fla., per ton	25.25
Furfural, tank cars	0.11
Fusel oil, refined, tanks, delivered	0.20
Fustic extract, cryst., No. 1 bbl, l.c.l.	0.47
Gelatin, pure food	0.57
Glycerol, crude, sapon., tanks, delivered	0.23
High-gravity, l.c.l., delivered	0.30
Synthetic, tanks and c.l.	0.30

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Glycerol dichlorohydrin, drums, l.c.l.	$ 0.37
Glycerol triacetylricinoleate, tanks	0.40
Glycine (aminoacetic acid), tech., works	1.25
Glycol boriborate, drums	0.31
Glyoxal, 30%, tanks and c.l., works	0.18
Green, chrome, light, medium, and dark, 250-lb min. bags, per 100 lb	38.00
Malachite, thioflavin toner, molybdic, bbl, works	4.50
Oxide, pure, per 100 lb	39.25
Phthalocyanine, standard, drums, lots	3.95
Pigment Green B, drums	1.35
Tungstated, brill., kegs	6.00
Guaiacol, tech., drums	1.79
Carbonate, cryst., small quantities	2.10
Guai-a-phene, drums, l.c.l., works	0.36
Guanidine carbonate, works	0.70
Hydrochloride, drums, works	0.42
Nitrate, bags, works	0.23
Gum arabic, amber sorts, bags, F.O.B. New York	0.18
Cellulose (purif. CNC), high vis., bags and drums, 23,000-lb lots or more	0.60
Ester, gum, wood-rosin, drums, c.l., delivered	0.16
Heptanal, tech., drums, works	0.95
Heptane, group 3, indust., refinery, tanks, per gal	0.23
Hexadecyl amine (from fats), dist., drums, c.l., works	0.52
Hexadecylammonium acetate, dist., drums, c.l., works	0.47
n-Hexadecyl- and *n*-octadecylammonium acetate, mixed, tech.	0.27
Hexamethylenetetramine, etc., bags, drums, over 1,000 lb	0.23
Hexane, industrial, tanks, per gal	0.14
Hexanol, drums, tanks, and c.l.	0.33
Hexylene glycol, tanks	0.14
Hexylresorcinol, USP, drums	14.00
Hydrazine, anhydrous, 2,200 lb, works	3.00
Disulfate, 2,000 lb, works	0.90

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Hydrate, 100%, 2,200 lb, works	$ 1.80
85%, 2,200 lb, works	1.35
Sulfate, comm	0.58
Hydrofuramide, drums	0.30
Hydrogen peroxide, 35%, tanks	0.18
Hydroquinone, tech., drums, works	0.77
Dimethyl ether, drums, l.c.l	1.60
Monomethyl ether, drums, l.c.l	2.60
8-Hydroxyquinoline benzoate, drums	4.50
Citrate, 100-lb lots	4.75
Hydrochloride, 100-lb lots	6.25
Phosphate, 100-lb lots	5.50
Salicylate, 100-lb lots	6.25
Sulfate, 100-lb drums	4.75
Hypernic, extract, liquid, bbl, l.c.l	0.27
Ichthammol, NF, 100-lb lots	0.75
Indalone, 20,000-lb lots and less, delivered	0.73
Indigo, 20% paste, synthetic, drums, l.c.l	0.31
Indole, 5-lb bottle	17.00
Inositol, meso-, 500-lb lots or more	4.50
Iodine, crude, kegs	1.15
Iodoform, powd., NF, drums, 100-lb lots	4.90
Iron, powd., reduced by hydrogen, NF, 100-lb lots, drums	0.90
Isoborneol, drums	1.25
Isobornyl acetate, drums	0.67
Propionate, drums	1.15
Isobutyl acetate, tanks, works	0.11
Anthranilate	7.25
Benzoate, 50-lb lots	1.35
Formate, drums, works	0.80
Methacrylate, drums, works	0.60
Propionate, drums, works	1.45
Salicylate, small quantities	2.20
Thiocyanoacetate, tanks, works, per gal	3.75
Isopentane, drums, works	0.43
Isophorone, tanks, works	0.22

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Isopropyl acetate, tanks, delivered	$ 0.10
Benzoate, tanks	0.22
Isopropyl phenylcarbamate, 20,000-lb lots and less	0.75
70% in xylene, trucks, l.c.l.	0.70
m-Isopropylamine, tanks, delivered	0.28
Isopropylbenzene, tanks	0.11
Isopropylphenol, *o*-, *p*-, and *m*-, mixed, tanks	0.45
Kaolin (China clay), Fla., purif., crushed, per ton	18.75
N.J., insecticide, per ton	16.00
Pa., paper, bulk, c.l., per ton	17.60
Rubber, coating, bags, c.l., per ton	13.50
Lactose (milk sugar), USP, drums, 30,000-lb lots, works, F.O.B. N.Y. State	0.24
Crude, bags, 36,000-lb lots or more, F.O.B.	0.15
Lauramide (from coconut), trucks or c.l., works	0.39
Lauryl acetate, drums	4.00
Lauryl chloride, dist., drums, l.c.l.	0.74
Laurylamine (from coconut), tech., c.l., works	0.58
Lead, metal, pig, c.l.	0.14
Acetate, gran., or powd., tech., bbl	0.23
Arsenate, bags, c.l., works	0.27
Carbonate, basic (white lead), bags, l.c.l.	0.16
Chloride, powd., tech., bbl	0.45
Linoleate, 26½%, fused, drums	0.32
Metallic paste, drums, 10,000–40,000-lb lots, works	0.33
Naphthenate, 24% Pb, liquid, drums, tanks, and l.c.l.	0.22
Nitrate, cryst., tech., bbl	0.22
Octoate, 24%, l.c.l.	0.27
Oleate, fused, bbl, l.c.l.	0.29
Oxide, red, dry, l.c.l., bbl or drums, works	0.17
Orange mineral, l.c.l., bbl or drums, works	0.19
Peroxide, 88½–90½%, powd., tech., 2,000-lb lots	0.38
Phosphite, dibasic, drums	0.57
Phthalate, dibasic, drums	0.39
Resinate, 23% Pb, precip., drums	0.30

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Salicylate, normal, drums, works	$ 0.46
Silicate (white), basic, bags, l.c.l.	0.18
Mono-, l.c.l., works	0.15
Ortho-, silica gel, 50–60% Pb, drums, works	0.31
Stearate, precip., bbl, l.c.l.	0.35
Sulfate, basic, blue or white, bbl, bags, c.l.	0.14
Tribasic, drums, works	0.26
Tallate, 24% Pb, liq., drums, l.c.l.	0.20
Tetraacetate, 85–95%	4.00
Tetraethyl lead, motor mix, tanks	0.37
Lecithin, edible, bleached, tech., drums, l.c.l., works	0.16
Lignin, extract, tanning, bags, c.l., works	0.05
Lime, hydrated, paper bags, works, per ton	10.00
Limestone, ground, bags, works, per ton	3.50
Lindane, tech., 20,000-lb lots	2.75
Litharge, powd., comm., bbl, l.c.l., works	0.16
Lithium, metal, lumps, 1-lb cans	13.00
Bromide, l.c.l.	2.13
Carbonate, powd., MF, drums	1.05
Chloride, drums	2.00
Citrate, 1,000-lb lots, drums	1.59
Fluoride, bbl	2.00
Hydroxide, monohydrate, drums	1.10
Hydroxystearate, l.c.l.	0.98
Salicylate, NF, bbl	1.60
Stearate, l.c.l., works	0.62
Lithopone, old., bags, l.c.l.	0.07
Titanated, bags, l.c.l.	0.10
Magnesia, calcined, USP, light and heavy, works	0.36
Synthetic, rubber, works	0.30
Magnesite, calcined, chemical, bags and c.l., works, per ton	82.50
Magnesium, metal, 99.8% ingots, c.l., works	0.27
Arsenate, bags, works	0.20
Bromide, small quantities	1.12
Carbonate, tech., bags, l.c.l.	0.09

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Chloride, anhydrous, lump, c.l., works	$ 0.12
Fluoride, bbl	0.20
Fluosilicate (silicofluoride), bbl, works	0.12
Glycerophosphate, NF, drums, works	5.40
Hydroxide, powd., NF, bbl	0.23
Hypophosphite, drums	1.97
Laurate, drums	0.46
Oleate, fused, bbl	0.31
Peroxide, 15%, drums, works	1.00
Phosphate, powd., purif., dibasic	0.64
Salicylate, pharmaceutical, drums, works	2.30
Stearate, purified and impalpable powd., boxes, l.c.l.	0.38
Sulfate, tech., bags, c.l., works, per 100 lb	2.15
Trisilicate, medium powd., USP, drums	0.38
Maleic, anhydride, drums, l.c.l.	0.28
Manganese, metal, 96% min., c.l.	0.30
Acetate, 22% Mn, bbl	0.35
Arsenate, bags	0.16
Borate, tech., bbl	0.24
Carbonate, bbl	0.21
Chloride, anhydrous, works	0.20
Dioxide, Africa, 84–87%, bags, c.l., works, per ton	83.00
Glycerophosphate, NF, drums, works	4.80
Hydrate, 65% Mn, bbl, delivered	0.36
Hypophosphite, NF, drums	2.00
Naphthenate, 6% Mn, liquid, drums, l.c.l.	0.25
Oleate, precip., bbl	0.33
Ore, 48%, c.i.f., long-ton unit	1.18
Resinate, 3½% Mn, fused, drums	0.23
Stearate, l.c.l.	0.38
Sulfate, 70%, tech., bags, l.c.l., delivered, per ton	75.00
Tallate, 6% liquid, l.c.l.	0.22
Mannitol, l.c.l., drums, works	0.38
Mercaptobenzothiazol, ton lots and 50-lb pack	0.38
Mercaptoethanol, 4,000-lb lots and less, works	1.25
Mercuric chloride (corrosive sublimate), gran. or powd., NF, drums, 100-lb lots	4.78

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Cyanide, cryst., powd.	$ 6.39
Iodide, red, NF, drums	7.72
Yellow, NF, drums	8.00
Nitrate, purif., cryst., small quantities	5.04
Oxide, red, tech., drums	5.27
Mercurous chloride (calomel), drums	4.97
Cyanide	6.84
Mesityl oxide, tanks	0.11
Metaldehyde, drums, works	0.95
Methoxychlor, 50%, wet powd. bags	0.61
2-Methoxyethanol (methyl Cellosolve), tanks, delivered	0.18
2-Methoxyethyl acetate, tanks, works	0.27
Methoxymethoxyethanol, c.l.	0.28
Methyl abietate, drums, l.c.l., delivered	0.19
Hydrogenated, drums, c.l., delivered	0.20
Acetate, 97–99%, drums, l.c.l., delivered	0.45
Acetoate, tanks, delivered	0.51
Acetone, natural, drums, extra, l.c.l., per gal	0.57
Synthetic, tanks, delivered, per gal	0.45
Acetylriconolate, tanks	0.41
Acrylate, monomers, tanks	0.42
Amyl ketone, drums, l.c.l., works	1.05
Benzoate, drums, works	0.53
Bromide, cyl.	0.67
Cellulose, bags, l.c.l., works	0.66
Chloride, indust., single-unit tanks, works	0.12
Tech., c.l., works	0.10
Chloroacetate, carboys, works	0.65
Cinnamate, 50-lb lots	1.55
Ethyl ketone, tanks	0.11
Formate, tech., tanks, drums, works	0.07
Hexyl ketone, tech., trucks, c.l., works	1.90
p-Hydroxybenzoate (methylparaben USP, methylparasept), drums, works	1.90
Iodide, CP, carboys	3.50
Isobutyl ketone, tanks	0.15
Lactate, drums, works	0.35

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Methacrylate monomer, tanks and c.l.	$ 0.42
n-Methylanthranilate	2.75
Naphthyl ketone, 50-lb lots	4.05
Nonyl ketone, small quantities	6.00
Phenylacetate, drums	0.75
Ricinoleate, tanks	0.41
Salicylate (oil of wintergreen), USP, drums	0.53
p-Toluenesulfonate	1.25
Undecylenate, dist., drums, works	1.75
Methylal, 95%, refined, tanks, works	0.09
Methylamines, mono-, 40%, soln., tech., tanks	0.31
Tri-, 25%, tanks and c.l.	0.33
Methylcyclohexanol, tanks	0.34
Methylene blue, USP, kegs, works	3.25
Chloride, tech., tanks	0.12
Methylethylpyridine, tanks	0.46
Methylmagnesium bromide in butyl ether	0.90
Methylphenylpyrazolone, bbl	1.70
β-Methylumbelliferone, works	1.85
Mica, dry-ground, paint, plastic, 100-mesh, bags, c.l., works	0.04
Milk powder, skimmed roller, bbl, c.l.	0.14
Molasses, blackstrap, tanks, La., per gal	0.10
Molybdenum, metal, 99% Mo, powd., kegs	3.00
Sulfide, pure gross	1.55
Molybdic trioxide (% Mo contained), tech.	1.14
Morpholine, tanks and c.l., delivered	0.52
Naphthalene, 74°, crude, comm., tanks, works	0.04
Refined, indust., tanks	0.09
α-Naphthol, tech., drums, delivered	1.00
β-Naphthol, flakes, powd., tech., bbl	0.32
α-Naphthylamine, l.c.l., delivered	0.50
β-Naphthylamine, tech., drums	1.10
Naphthyl ketone	3.65
Salicylate, USP	0.58
α-Naphthylthiourea, 93–98%, drums, works	2.00

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Neoprene, latex (Type 571), dry basis, tanks, Louisville	$ 0.37
Solid (Type GN-A), 50-lb bags, works	0.41
Nickel, metal, electrolyte cathodes, cases	0.60
Acetate, bbl, delivered	0.68
Carbonate, bbl	0.71
Chloride, bbl, delivered	0.37
Cyanide, drums	4.50
Formate, bbl, l.c.l., works	0.66
Nitrate, bbl, works	0.39
Oxide, black, bbl	0.69
Sulfate, l.c.l., delivered	0.29
Nicotine sulfate, 40%, drums	1.20
m-Nitroaniline, tech., drums	1.02
o-Nitroaniline, flakes, 10,000 lb and less, drums	0.54
p-Nitroaniline, kegs	0.51
Nitrobenzene, tech., tanks, works	0.11
o-Nitrobiphenyl, tech., drums	0.14
p-Nitrophenyl, l.c.l.	0.32
Nitrocellulose, ester-soluble, c.l., works	0.33
o-Nitrochlorobenzene, tanks, drums	0.18
p-Nitrochlorobenzene, l.c.l.	0.26
Nitroethane, drums, l.c.l., works	0.25
Nitrogen fertilizer soln., works, per ton	126.00
Nitromethane, drums, l.c.l., works	0.25
α-Nitronaphthalene, tech., drums	0.41
o-Nitrophenol, drums	0.94
p-Nitrophenol, drums, works	0.50
Nitropropane, No. 1, drums, works	0.23
o-Nitrotoluene, tech., tanks, delivered	0.09
p-Nitrotoluene, drums, delivered	0.33
m-Nitro-*p*-toluidine, l.c.l., works	1.59
Nonylphenol, l.c.l.	0.29
Octadecyl nitrile, dist., c.l., works	0.42
2-Octanol, drums, works	0.41
Octyl formate, small quantities	2.25
Isobutyrate, small quantities	4.95

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Octylphenol, tank cars and tank trucks, works	$ 0.22
Oil:	
Castor, standard, No. 1, tanks	0.17
Coconut, crude, tanks	0.11
Cod-liver, USP, drums, per gal	1.55
Corn, crude, tanks, works	0.14
Cottonseed, crude, tanks, works	0.14
Linseed, raw, tanks, works	0.15
Menhaden, crude, tanks and c.l.	0.07
Mineral white, 50–65 viscosity, tech., drums, c.l. per gal	0.51
Neat's-foot, 20°, drums	0.33
Oiticica, drums, l.c.l.	0.17
Oleo, extra, drums	0.18
Olive, comm., drums, per gal	2.30
Palm, tanks	0.11
Peanut, crude, tanks, works	0.18
Pine, dest. dist., l.c.l., works	0.11
Soybean, crude, tanks	0.14
Sperm, bleached, winter 45°, tanks	0.14
Tall, crude, tanks, works, per ton	40.00
Tallow, acidless, drums	0.10
Tar, pine, comm., tanks, per gal	0.33
Rect. or NF, drums, l.c.l., per gal	0.90
Tung, tanks and drums, c.l.	0.21
Oleostearin, bbl	0.12
Orange, cadmium, lithopone, drums	0.61
Chrome, 250-lb min., bags	0.31
Dinitroamine, standard, drum lots	1.30
Molybdate, 250-lb min., bags	0.44
Oxamide, drums	2.75
Oxygen, cyl., works, per 100 cu ft	1.30
Paraffin, 42%, chlorinated, drums, l.c.l.	0.14
Paraformaldehyde, 91%, flake, l.c.l., delivered	0.10
Paraldehyde, 98%, tech., c.l., delivered	0.11
Paris green, drums, kegs, c.l.	0.36

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Pentachloroethane, drums, works	$ 0.12
Pentachlorophenol, l.c.l., works	0.21
Pentaerythritol, tech., bags, trucks, l.c.l.	0.32
Perchloroethylene, tanks, works	0.10
Petroleum, mineral spirits, tanks, per gal	0.17
Phenol, 90–92%, tanks and trucks, works	0.14
40°, tanks and c.l.	0.16
Phenolphthalein, powd., USP	1.10
Phenothiazine, NF, drums, l.c.l.	0.53
Phenyl diethanolamine, l.c.l., delivered	0.40
Isocyanate, carboys, drums, works	2.00
Phenylacetaldehyde, pure, works, small quantities	4.30
Magnesium bromide, in ethyl ether, 500-gal lots	0.98
Salicylate, gran., NF, l.c.l.	1.10
Phenylacetamide, 1,000-lb lots	1.10
dl-Phenylalanine, drums, works, l.c.l.	27.00
m-Phenylenediamine, tech., drums	0.90
o-Phenylenediamine, 100-lb drums	2.65
p-Phenylenediamine, l.c.l.	1.40
Phenylethyl acetate, cans	1.70
2-Phenylethyl phenylacetate, small quantities	3.95
β-Phenylethylamine, 1,000-lb lots	1.10
Phloroglucinol, comm., works	6.40
Phosgene, tech., 150-lb cyl., works	0.27
Phosphate, crude, rock, run-of-mine, washed, dried, c.l., per ton	4.68
Tricresyl, coal tar, petroleum, drums, l.c.l., delivered	0.35
Triethyl, drums, c.l., works	0.39
Phosphorus, red, amorph., cases	0.45
Wedges, drums, works, per 100 lb	21.00
Yellow, solid, drums, tanks, per 100 lb	17.00
Oxychloride, tanks and c.l.	0.12
Pentasulfide, solid, drums, works	0.11
Pentoxide, drums, l.c.l.	0.13
Sesquisulfide, cases, works	0.33
Trichloride, tanks and c.l.	0.12
Phthalic anhydride, tanks and c.l.	0.19

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Phthalimide, 100%, bbl, works	$ 0.65
α-Picoline, drums, l.c.l., works	0.43
β-Picoline, drums, l.c.l., works	1.05
Pine tar, retort, tanks, per gal	0.35
Piperidine, dist., drums, works	2.90
Piperonyl butoxide, tech., works	4.50
Cyclonene, tech., same basis	3.70
Pitch, coal tar, bbl, c.l., works, per ton	41.20
Pine, 500-lb drums, works	0.08
Tall oil, c.l., works	0.03
Platinum, metal, per troy oz	84.00
Polyethylene glycol, liquid (Carbowax), Nos. 200, 300, 400, 600, tanks or compartment tanks and c.l., delivered, East	0.22
Solid (Carbowax), Nos. 1,000, 1,500, drums, tanks, and c.l., delivered, East	0.29
No. 4,000, 6 or more bags, delivered	0.31
No. 6,000, same basis	0.35
Polyisobutylene	0.32
Polystyrene, cryst., reg., l.c.l.	0.32
Polyvinyl acetate, gran., drums, c.l., 30,000-lb lots	0.41
Emulsion, tanks	0.20
Potassium, metal, bricks, pails	3.66
Acetate, anhydrous, l.c.l.	0.28
Acid tartrate, 5,000-lb to c.l., drums, F.O.B.	0.32
Antimonyl tartrate (tartar emetic), tech	0.56
Bicarbonate, powd., drums	0.24
Bichromate, gran., bags, c.l., or truckloads, works, per 100 lb	15.00
Bisulfate, AR, cryst., small quantities	0.81
Borate, gran., bbl, c.l., works, per ton	180.00
Bromate, purif., powd., and gran., drums	0.50
Bromide, gran., USP, l.c.l., bbl	0.32
Carbonate, calcined, 99–100%, bags, l.c.l., per 100 lb	8.75
Hydrate, 83–85%, bags, c.l., per 100 lb	7.35
Liquid, 47%, tanks, per 100 lb	3.50
Chlorate, powd., drums, works	0.10

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Chloride, chem. (99.9% KCl), mines, per ton	$ 27.00
Chromate, tech., kegs, bbl	0.45
Citrate, gran., NF, drums	0.41
Creosote sulfonate, drums	2.90
Cyanate, c.l., works	0.60
Cyanide, drums, works	0.55
Ferric cyanide, bbl	0.63
Ferrocyanide, bbl	0.22
Fluoride, l.c.l., drums, works	0.32
Glycerophosphate, 50-lb carboys	2.30
Guaiacosulfonate, NF, drums	2.10
Hydroxide, flake, 90%, drums, l.c.l., works, per 100 lb	9.15
Liquid, 45%, drums, c.l., per 100 lb	4.25
Solid, 90%, drums, c.l., works, per 100 lb	8.70
Hypophosphite	1.00
Iodide, cryst., powd., and gran., USP, drums	2.15
Magnesium sulfate, per ton	16.00
Manure salts, run-of-mine, 22% K_2O, per unit	0.21
Metabisulfite, gran., drums, 100-lb lots	0.20
Muriate, agricultural, 60% K_2O, bulk, 40-ton lots, per unit	0.35
Nitrate, gran., bags, c.l., per 100 lb	9.00
Oxalate, neutral, tech., fine gran., bbl	0.30
Perchlorate, drums, c.l., works	0.15
Permanganate, tech., kegs, works	0.22
Persulfate, drums, l.c.l., works	0.18
Phosphate, tetra-, bbl, works	0.16
Ricinoleate, soln. (35% solids)	0.21
Silicate, glass, bags, c.l., per 100 lb	17.00
Silicofluoride, bbl, works	0.09
Sodium tartrate, gran., powd.	0.32
Stannate, drums, 10,000-lb lots	0.68
Sulfate, powd., NF, drums	0.19
Fert., dom., bulk, 90–95% K_2SO_4, works, per ton	36.25
Sulfite, drums	0.26
Thiocyanate, cryst., tech	0.79
Titanate, c.l., works	0.12

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Procaine hydrochloride, USP, 1,000-lb lots	$ 2.90
Propane, liquefied gas, comm., tanks, per gal	0.03
Propyl gallate, purif., 2,000- and 1,000-lb lots	3.90
p-Hydroxybenzoate, tech.	2.00
n-Propyl acetate, tanks and c.l., works	0.10
n-Propylmagnesium bromide, in ethyl ether, cans	2.50
Propylene carbonate, l.c.l.	0.55
Dichloride, tanks and c.l., delivered	0.07
Glycol, indust., tanks and drums, c.l., delivered	0.13
Oxide, tanks and c.l.	0.15
Pyridine, ref., 2°, drums, l.c.l.	0.94
Pyrites, domestic and Can., F.O.B., per long ton	9.00
Pyrogallol, powd., tech., drums	2.50
Pyrophyllite, bulk, mines, c.l., per ton	11.00
Pyroxylin, scrap plastic, ½-in. mesh, translucent, pastels	0.14
Quebracho, liquid, bbl, works	0.08
Quinizarine, l.c.l.	1.50
Quinoline, drums, works, tanks, l.c.l.	0.50
Red, Alizarin lake toner, bbl	4.79
Cadmium, toner, drums	4.00
Carmine, No. 40, NF	7.80
Iron oxide, synthetic, pure, bags	0.12
Lithol, rubine, drums	1.40
Oxide and Indian, red, pure, c.l., works, per 100 lb	0.12
Paratoner, bbl, delivered	0.95
Scarlet, pigment, drums	1.40
Toluidine, toner, bbl	1.50
Tuscan, c.l., works, per 100 lb	24.50
Venetian, c.l., works, per 100 lb	3.50
Resorcinol, tech., drums, l.c.l.	0.77
Rosin, gum, M, Southern, per 100 lb	7.82
Rotenone, cube powder, 5% basis, 20,000-lb lots or more, works	0.24
Saccharin, gran., USP, drums, 1,000-lb lots or more	1.60
Salicylamide, drums, works	1.30

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Salt, rock, bags, l.c.l., per 100 lb	$ 0.98
Selenium, 99½%, black powd.	5.00
Semicarbazide hydrochloride, drums	4.75
Shellac, pure TN, bags	0.47
Silica, superwhite, bags, works, c.l., per ton	23.00
Silicon tetrachloride, tech., tanks	0.15
Silver chloride, per oz	0.78
Cyanide, per oz	0.77
Nitrate, cryst., CP, per oz	0.55
Oxide, per oz	0.86
Sodium, metal, tank cars	0.16
Acetate, 60%, tech., l.c.l.	0.08
Aluminate, bags, works, per 100 lb	8.50
p-Aminobenzoate, drums	2.50
p-Aminosalicylate, 1,000-lb lots	3.75
Antimonate, works, l.c.l.	0.26
Arsenate, drums, c.l., works	0.12
Benzoate, tech., drums	0.39
Bicarbonate, powd., USP, bags, l.c.l., works, per cwt	2.30
Bichromate, gran., bags, c.l. or truckload, works, per 100 lb	11.50
Bifluoride, bbl, c.l., works	0.13
Bisulfate, bulk, per 100 lb	2.00
Bisulfite, powd., bags, c.l., works, per 100 lb	4.50
Bromide, gran., USP, l.c.l., bbl	0.32
Carbonate, dense ash, 58%, bulk, c.l., works, per 100 lb	1.40
Light, 58%, bulk, c.l., works, per 100 lb	1.35
Monohydrated, bags, c.l., works, per 100 lb	2.90
Carboxymethyl cellulose, 80% active CMC, low and med. viscosity, 23,000-lb lots and less	0.39
Chlorate, cryst., drums, c.l., works	0.08
Chlorite, tech., works	0.58
Chloroacetate, tech., drums, works	0.27
Chromate, anhydrous, drums, c.l. or truckloads, works, per 100 lb	0.13

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Citrate, gran., USP, bags, drums	$ 0.24
Cyanate, 1,000-lb lots, works	1.00
Cyanide, 96%, drums, l.c.l.	0.17
Diacetate, tech., drums, works	0.10
Ferrocyanide, bags, works	0.13
Fluoride, 95%, l.c.l., works	0.11
Fluoroacetate, monobasic, works	12.00
Formate, l.c.l., bags	0.07
Gluconate, tech., bags, works	0.35
Glutamate, mono-, 100-lb drums, l.c.l., delivered	1.55
Glycerophosphate, 75% soln., 1,000-lb lots	1.35
Hydrosulfite, drums, l.c.l., delivered	0.23
Hydroxide, flake, 76%, ground or powd., drums, l.c.l., per 100 lb	4.25
Liquid, 70–74%, tanks (basis 76%), per 100 lb	2.80
Liquid, 50%, tank cars (basis 76%), per 100 lb	2.70
Solid, 76%, drums, l.c.l., per 100 lb	3.85
Hypophosphite, comm., l.c.l.	0.50
Hyposulfate, pea cryst., bags	0.04
Hyposulfite, cryst., tech., bags, l.c.l., works	0.04
Iodide, USP, drums	2.80
Lactate, 50%, tech., dark and light, works, F.O.B.	0.16
Lauryl sulfate, USP, l.c.l.	0.25
Metasilicate, anhydrous, bags, l.c.l., per 100 lb	5.10
Pentahydrate, bags, l.c.l., works, per 100 lb	4.00
Molybdate, anhydrous (% of Mo contained), any quantity, works	1.82
Nitrate, Chilean, bulk and bags, Atlantic ports, c.l., per ton	49.50
Domestic, synthetic, bulk and bags, c.l., works, per ton	43.50
Nitrite, bbl, l.c.l., works, per 100 lb	7.75
Orthosilicate, anhydrous, drums, c.l., works, per 100 lb	6.00
Oxalate, bags, works	0.10
Perborate, tetrahydrate, NF, bbl, l.c.l., works	0.17
Peroxide, drums, l.c.l.	0.18

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Phenolsulfonate, gran., USP, drums	$ 0.44
Phosphate, monobasic, anhydrous, bags, l.c.l., works, per 100 lb	8.50
Dibasic, anhydrous, bags, l.c.l., per 100 lb	7.45
Tribasic, bags, l.c.l., per 100 lb	4.20
Pyrophosphate, bags, c.l., works	0.10
Tripoly-, 100-lb bags, l.c.l., per 100 lb	8.05
Sesquicarbonate, bulk and bags, c.l., works, per 100 lb	1.85
Sesquisilicate, anhydrous, drums, c.l., works, per 100 lb	5.50
Hydrate, bags, bbl, c.l., works, per 100 lb	4.60
Silicate (water glass), 40° liquid, tanks, trucks, and c.l., works, per 100 lb	1.00
Silicofluoride, bbl, c.l.	0.07
Stannate, drums, 2,000- to 9,900-lb lots	0.544
Stearate, tech., c.l., works	0.39
Sulfate, anhydrous, tech., bags, c.l., works, per 100 lb	2.35
Sulfhydrate, 70–72%, flake, drums, l.c.l., works, per ton	130.00
Sulfide, flake, l.c.l., per 100 lb	5.25
Sulfite, anhydrous, powd., bbl, l.c.l., per 100 lb	7.25
Sulfoxylate formaldehyde, l.c.l.	0.22
Tetrasulfide, 40%, drums, l.c.l., works	0.03
Thiocyanate, tech., cryst.	0.71
Tungstate, tech., cryst., drums, works	2.00
Solvent naphtha, coal tar, tanks, c.l., works, per gal	0.31
Sorbitan, monooleate, drums, 2,000–20,000-lb lots, works	0.35
Monostearate, same basis	0.32
Sorbitol, soln., aqueous, comm., l.c.l., works	0.23
70% reg., aqueous, tanks, l.c.l.	0.15
Soya fatty amine, tech.	0.35
Acetate, tech.	0.34
Stannic chloride, anhydrous, drums	0.76
Oxide, drums	0.93
Stannous chloride, anhydrous, l.c.l., works	0.81
Oxide, 2,000-lb lots, works	1.32
Sulfate, works	0.92

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Starch, corn, bags, c.l., per 100 lb	$ 7.14
Potato, bags, c.l., per 100 lb	6.50
Stearamide, powd., c.l., works	0.37
Stearyl amine acetate, c.l., drums, works	0.36
Strontium bromide, gran., NF, drums	0.77
Carbonate, drums	0.19
Chromate, bbl, delivered	0.46
Nitrate, bbl, c.l., works	0.11
Salicylate, NF, drums	1.65
Strychnine, powd., NF, small quantities, per oz	1.10
Styrene, monomer, tanks, works	0.21
Succinimide, gran., drums	3.52
Sucrose, 99.96%, bags, per cwt	8.65
Octaacetate, denat., drums, works	0.76
Sulfur, crude, agricult., indust., bulk, c.l., mines, per ton	26.50
Dichloride, drums, tanks, c.l.	0.03
Dioxide, liquid, comm., tank cars, c.l., works	0.04
Superphosphate, run-of-pile, bulk shipment, per unit ton	0.88
Triple, bulk, per unit ton	0.98
Talc, Vt., bags, works, per ton	14.00
Tallow, inedible, extra, c.l.	0.06
Tech.	0.31
m-Amine acetate, tech.	0.27
Tar, pine, tanks, works	0.04
Tellurium, metal, pulv., cans, works	3.00
Terpineol, drums, works	0.45
α-Terpineol, drums, l.c.l., works	0.17
Terpinyl acetate, tech. and extra, drums	0.57
Tetrachloroethane, drums, works	0.14
Tetrachloroethylene, USP, drums, works, l.c.l.	0.20
Tetraethyl orthosilicate, drums, works	0.65
Pyrophosphate, 40%, drums	0.69
Tetraethylene glycol dimethyl ether, drums	1.10
Tetraethylenepentamine, tanks and c.l., delivered	0.56
Tetrahydronaphthalene, drums, l.c.l., delivered	0.30
Thallium sulfate, bottles, delivered	8.00
Theobromine, sodiosalicylate, NF, 25- and 100-lb lots	3.20

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Theophylline, USP, lots, drums	$ 3.65
Thiocarbanilide, drums	0.44
Thiosemicarbazide, drums	4.75
Thiouracil, drums, works	5.50
Thiourea, tech., drums, l.c.l., works	0.40
Tin, metal	0.93
Titanium, metal, 96–98½%, sponge	5.00
Rutile calcium pigment, 30%, bags, l.c.l.	0.08
Dioxide, pigments, anatase, bags, l.c.l.	0.22
Rutile, bags, l.c.l.	0.24
Tetrachloride, tech., l.c.l., works	0.45
Trichloride, 23% soln., carboys, l.c.l., works	0.32
m-Tolualdehyde	2.85
Toluene, coal tar, works, per gal	0.32
m-Toluidine, l.c.l.	0.78
o-Toluidine, tanks, delivered	0.22
p-Toluidine, cast and flaked, works, delivered	0.61
Toxaphene, drums, works, l.c.l.	0.19
Triacetin, tanks, c.l., delivered	0.37
Tributyl acetylcitrate, tanks, c.l.	0.32
Citrate, tech., tanks, c.l.	0.39
Phosphate, tanks and c.l.	0.50
Tributylamine, tanks	0.72
1,2,4-Trichlorobenzene, tanks	0.13
Trichlorcethane, tanks and c.l., works	0.11
Trichloroethylene, tanks	0.10
2,4,5-Trichlorophenoxyacetic acid, l.c.l., works	1.40
Triethanolamine, tanks and c.l., delivered	0.21
Triethyl citrate, tanks	0.36
Orthoformate, 4,000-lb lots, works	1.10
Phosphate, tanks and c.l.	0.37
Triethylamine, tanks, c.l., delivered	0.45
Triethylene dimethyl ether, cans and drums	1.10
Glycol, tanks and c.l., delivered	0.18
Tetramine, tanks, delivered	0.47
Triisobutylene, l.c.l., drums	0.09
Trimethylamine, tanks, cyl., works	0.33

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
3,3,5-Trimethylcyclohexanol-1, drums, works	$ 0.75
3,3,5-Trimethylhexanol-1, tanks, works	0.27
Trimethylol ethane, bags, l.c.l.	0.40
Propane, drums, l.c.l.	0.65
2,2,4-Trimethylpentane, cert., drums, per gal	0.80
Tripentaerythritol, drums or bags, 30,000-lb lots, works	0.35
Triphenyl phosphate, bbl	0.39
Triphenylguanidine, bbl, works, delivered	0.90
Tungsten, metal, 98.8%, 1,000-lb lots, works	4.95
Tungstic, oxide, over 1,000-lb lots, drums, works	2.25
Turpentine, gum, bulk, per gal	0.50
Wood-steamed distilled, l.c.l., drums, per gal	0.75
Urea, 42% N, fert., bulk, c.l., per ton	114.00
46% N, cryst., indust., bags, l.c.l., works	0.06
Urea-formaldehyde composition (Arboneeld A), l.c.l.	0.20
Vanillin, eugenol, small quantities	6.75
Guaiacol, small quantities	3.00
Lignin, tins	3.00
Vinyl acetate, tanks, c.l., delivered, East	0.16
Butyl ether, tanks and c.l.	0.27
Chloride, tanks, works	0.13
Ethyl ether, tanks and c.l.	0.27
Vinylidene chloride	0.14
2-Vinylpyridine, drums, l.c.l., works	1.40
Wax, bees-, crude, imported, bags	0.55
Candelilla, crude	0.66
Carnauba, No. 3, refined	0.76
Japan, bags	0.45
Opalwax, synth., c.l.	0.37
Spermaceti, cakes	0.26
Whiting precipitate, bags, c.l., per ton	18.00
Xylene, coal tar, indust., per gal	0.32
Yeast, brewer's, 200 B units per gm, 200-lb lots and more, drums	0.56

Table 33. Prices of Chemicals (*Continued*)

Chemical	*Price*
Yellow, cadmium toners, drums	$ 2.75
Lithopone, drums	1.20
Benzidine, drums	1.91
Chrome, bags	0.31
Hansa, bbl	1.91
Iron oxide, synthetic, bags, l.c.l., works	0.10
Zein, bags, works	0.38
Zinc, metal, slabs	0.11
Acetate, drums, l.c.l.	0.25
Ammonium chloride, bags, works	0.09
Borate, bags, l.c.l.	1.19
Carbonate, tech., bags, bbl, c.l., works	0.12
Chloride, tech., fused, drums, c.l., works, per 100 lb.	10.10
Chromate, works	0.25
Cyanide, kegs, drums, works	0.54
Dust, bbl, l.c.l., works	0.14
Fluoride, bbl, l.c.l., works	0.49
Hydrosulfite, drums, l.c.l.	0.21
Naphthenate, liquid, 8% Zn, l.c.l.	0.23
Oleate, fused, bbl	0.36
Oxide, Amer. process, lead-free, bags, l.c.l.	0.13
Peroxide, tech., drums, works	0.71
Phenolsulfonate, gran., NF, drums	0.39
Resinate, precip., 7.4% Zn, drums	0.28
Silicofluoride, bbl, l.c.l.	0.14
Stearate, Disperso grade, l.c.l.	0.38
Lacquer, tech., l.c.l.	0.37
Sulfate, cryst., 22½% Zn, bags, works, l.c.l.	0.07
Sulfide, tech., purif., bags, works, l.c.l.	0.25
Sulfoxylate formaldehyde, basic, l.c.l.	0.25
Tallate, liquid, 8% Zn, works	0.21
Zirconium acetate, bbl, works	0.23
Carbonate, basic, bbl, works	0.30
Oxide, white ground, bags, works	1.50
Oxychloride, cryst., works	0.35
Silicate, gran., bags, works, 100-lb lots	3.12
Sulfate, cryst., works	0.37

Labor

The second major direct expense is that of labor, which consists of the wages paid to employees whose efforts are directed solely toward product manufacture. In large-scale liquid or gaseous processes, labor represents only 5 to 10 per cent of the manufacturing expense; in operations involving considerable handling, wages may be 15 to 25 per cent. The chemical industry is known to employ one person for every $25,000 of existing investment. For new expenditures the value is almost $40,000.[18, 22, 23, 36, 38, 42]

Table 34. Labor Requirements for Various Processes

Process	*Man-hr per ton of product*	Process	*Man-hr per ton of product*
Acetic acid from carbide	29	Oxygen, small-scale	48
Alumina, Bayer process	3.7	Oxygen, 95%, large-scale	0.2
Aluminum sulfate	1.5	Phenol	8.5
Ammonium phosphate	0.7	Phosphoric acid, blast furnace	3.0
Calcium carbide	3.0	Phosphoric acid, Dorr process	1.7
Calcium cyanamide	5.5	Phosphoric acid, electric furnace	0.8
Cellulose acetate	80	Soda ash	3.5
Cellulose nitrate	60	Sodium	13
Cement	2.1	Sodium bichromate	15
Ethanol from molasses	3.1	Sodium chlorate	8.0
Ethylene glycol	9.0	Sodium hydroxide and chlorine, from salt	9.5
Gasoline, catalytic	0.2	Sodium hydroxide–lime soda process	0.9
Gasoline, natural	1.5	Sulfur dioxide, liquid	10
Gasoline, polymer	0.5	Sulfuric acid	0.6
Hydrochloric acid, synthetic	3.2	Urea	1.6
Hydrochloric acid from salt	5.2	Zinc oxide	5.0
Lactose	24		
Magnesium, electrolytic	27		
Nitric acid	1.0		

Unfortunately, there is no short-cut method universally applicable for estimating labor requirements. The best method by which manpower needs may be evaluated is by study of the flow of materials through process operations and the equipment performance with relation to the cycles of operation.

Table 34 shows labor requirements in man-hours per ton of product for a number of specific industries.

Figure 82, an excellent correlation devised by Wessel, is a convenient means of estimating approximate manpower requirements. The plot has as its abscissa the plant capacity in tons per day; the ordinate is man-hours per ton per step. In using this method, a count is made of the number of primary operational steps, such as filtration, electrolysis, distillation, and concentration. Then for the proper plant capacity, the value of man-hours per ton per step is found on the graph and multiplied by the number of process steps to give the total man-hours per ton of production. Figure 82 is shown for a range of values: the uppermost line represents manpower requirements for processes developing higher capacities by means of duplication of small units or for operations retaining batch characteristics; the lowest line is for installations using large-sized equipment, employing a high degree of automatic control, or processing only fluids; the middle line represents overall average conditions.[39]

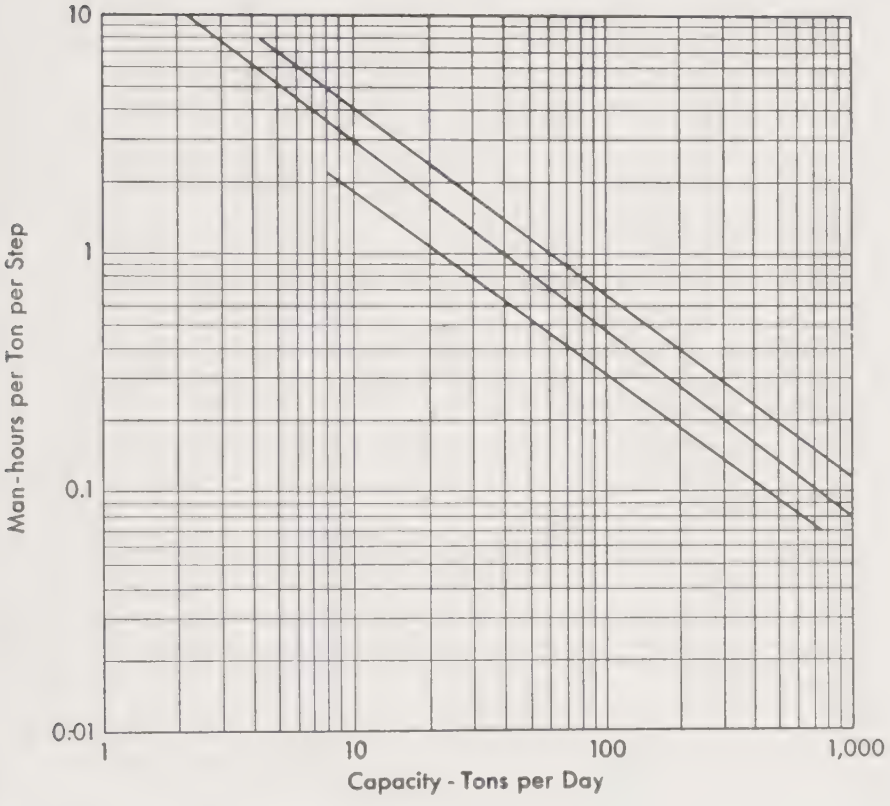


Fig. 82. Labor requirements.

Labor requirements for operating specific types of process equipment are listed in Table 35.

Table 35. Labor Requirements for Process Equipment

Equipment	*Men per unit*
Rotary dryer	0.5
Spray dryer	1.0
Tray dryer	0.5
Centrifugal separator	0.25–0.5
Vacuum crystallizer	0.25
Mechanical crystallizer	0.15
Vacuum filter	0.15–0.25
Evaporator	0.25
Size-reduction equipment	0.25–1.0
Tower	0.25
Batch still	1.0
Reactor, continuous	0.5
Reactor, batch	1.0

Labor rates are best judged from a company's prevailing scale. In their absence values reported by the Bureau of Labor Statistics or those listed in Table 36 may be employed. The estimator should be aware of possible increases in labor costs due to overtime, Sunday, holiday, or night operation.

Table 36. Hourly Wage Rates

Labor	*Hourly rate*
Unskilled	$1.50 $1.75
Skilled	1.75– 2.20
Squad leaders and foremen	2.20– 3.00

Supervision

Supervisory expense is the salaries of all personnel responsible for the direct supervision of productive operations. Salary scales vary with the degree of responsibility required. In many cases it may be possible to total directly the compensation of

all supervisory employees. Quick estimates may be prepared by applying a percentage of the labor charge equal to 10 per cent for simple operations and 25 per cent for complex procedures. Inasmuch as experience is one kind of measure of the type of personnel needed for a supervisory position, Table 37 is presented to show approximate salaries as a function of years of experience.[10, 22, 23, 26]

Table 37. Annual Supervisory Salaries

Years of experience	*Annual salary*
1	$4,500
5	6,000
10	8,000

Maintenance

Maintenance expenses include the cost of all materials and labor employed in routine maintenance and incidental repairs, and in some cases in major revisions of equipment and buildings. Under average operating conditions maintenance expense is composed of 50 per cent labor and 50 per cent materials.[8, 21, 23–25]

Not only are maintenance expenditures difficult to predict, but also certain types of expenses are sometimes incorrectly charged as such. Expenditures made to enhance the value of the plant should be regarded as capital investment; those due to obsolescence and normal wear are covered by depreciation; and items used in normal plant operation, such as gaskets, charts, and lubricants, are classified as plant supplies.

Preliminary determination of repair costs requires a knowledge of equipment performance in order to provide proper insight as to selection of a satisfactory charge. Any one of the subsequent three methods may be employed for maintenance estimation.

1. The first method is definitely the simplest, requiring the use of a charge equal to a percentage of the fixed-capital investment. Before a value is selected, consideration should be given to the degree of wear anticipated, inasmuch as considerable variance in rates will be found. It is suggested the ranges listed in Table 38 be employed

Table 38. Annual Maintenance Cost

(Equivalent to percentages of fixed-capital investment)

Type of equipment	*Annual maintenance, %*
Simple, light use	2–4
Average	6–7
Complicated, severe use	8–10

for determining the amount of annual maintenance expense. It should be remembered that employment of such values requires that the purchased price of the equipment in the fixed-capital cost be adjusted to the same index value as the maintenance expenditure.

2. For existing plants or processes where some cost information is already available, it may prove possible to arrive at a more satisfactory maintenance estimate by applying a method devised by Pierce. This means has as its basis the following formula:[24]

$$K = X(a + by)$$

where K = maintenance cost per year
X = electricity used per year, kwhr
a = material index, defined as the cost in dollars of repair material per kilowatthour used
b = labor index, defined as the man-hours of repair labor per kilowatthour used
y = cost per man-hour with overhead

3. The last method of computing maintenance costs requires a somewhat detailed compilation of repair expenses on each individual piece of equipment. Tables 39 and 40, which are based primarily upon an excellent compilation by Leonard, list maintenance expenses for many types of equipment and piping.[21]

Table 39. Maintenance Cost of Equipment *

Type of equipment	*Maintenance cost*
Centrifugal separators:	
Batch, top suspended or bottom driven, 20 in.	$ 200
48 in.	350
Batch, automatic, 18 in.	300
81 in.	2,000
Conveyor, 18 in.	300
54 in.	1,800
Conveyors:	
Belt, 100 ft	100
Screw, 100 ft	200
Bucket, 50 ft	600
Crystallizers:	
Batch, 2,000 gal	200
Swenson-Walker mechanical, 1.5 ft × 1.5 ft × 20 ft	100
Dryers:	
Drum	4/sq ft
Rotary, 6 ft × 30 ft	200
Spray, small	150
Large	350
Tray, atmospheric	2/sq ft
Vacuum	3/sq ft
Dust collectors:	
Cyclones	250/1,000 cfm
Filters	200/1,000 cfm
Washers	300/1,000 cfm
Electrical precipitator	600/1,000 cfm

* All figures are per year unless otherwise noted.

Table 39. Maintenance Cost of Equipment (*Continued*)

Type of equipment	*Maintenance cost*
Evaporators:	
Multieffect, 1,000 sq ft/stage	$ 500/stage
Glass-lined vessel	800/1,000 gal.
Filters:	
Plate and frame	1/sq ft
Leaf	2.50/sq ft
Rotary	10/sq ft
Heat exchangers:	
Condensers	0.30–2.00/sq ft
Jacketed pipe	0.75–3.00/sq ft
Reboilers	0.50–5.00/sq ft
Mixers:	
Light duty	200
Medium duty	300
Heavy duty	500
Pumps:	
Centrifugal, 30 gpm	100
100 gpm	150
200 gpm	240
Diaphragm, 30 gpm	500
60 gpm	700
Reciprocating, 30 gpm	160
60 gpm	225
Screens:	
Vibrating dry, 50 sq ft, electrical	600
Mechanical	800
Size reduction:	
Gyratory crushers, small	70
Large	400
Roller mills, small	2,000
Large	7,000
Ball mills, per ton ground	0.10
Impact mills, per ton ground	0.15
Mikropulverizers, per ton ground	0.06

Table 39. Maintenance Cost of Equipment (Continued)

Type of equipment	*Maintenance cost*
Tanks:	
Wood, neutral, alkaline, or weak acid under 50°C	$ 12/1,000 gal
Steel, neutral or alkaline	12/1,000 gal
Rubber-lined steel, weak acid under 50°C	40/1,000 gal
Plastic-lined steel, weak acid under 50°C	50/1,000 gal
Lead-lined steel, weak acid over 50°C	200/1,000 gal
Glass-lined steel	800/1,000 gal
Agitated	1,000/1,000 gal
Stainless steel, weak acid under 50°C	7/1,000 gal
Noncorrosive	5/1,000 gal
Haveg, weak acid over 50°C	8/1,000 gal
Aluminum, noncorrosive	5/1,000 gal
Thickeners:	
Continuous, 20,000 gal, noncorrosive	700
Corrosive	2,500
Towers:	
Bubble plate	5–50/cu ft
Packed	5–15/cu ft

Table 40. Maintenance Costs of Piping

Type of piping	Maintenance cost per 100 ft per year			
	1 in.	2 in.	4 in.	6 in.
Steel	$10	$20	$30	$50
Cast iron	6	12	20	25
Stainless steel	7	14	22	28
Glass	22	40	60	80

Plant Supplies

In the previous section on maintenance it was noted that items used by plant personnel in the normal operation of equipment, such as gaskets, charts, and lubricants, while closely allied to maintenance, are properly classified as plant supplies. The expense incurred in their purchase may be approximated as an amount equivalent to 15 per cent of maintenance costs annually.[22, 23, 36]

Royalties and Patents

The cost of patents purchased for production purposes is customarily amortized over their legally protected lives. Royalties are generally paid at a specified rate on either a production or sales basis. In the absence of exact rates, a value equivalent to 1 to 5 per cent of the sales price of the product may be employed for estimating royalty or patent costs.[22, 36]

Utilities

The quantities of steam, water, electric power, fuel, compressed air, and refrigeration used must be determined by the engineer from a study of process requirements. It is suggested that the calculated amounts be increased by 25 to 50 per cent to compensate for building and service needs, losses, and contingencies.[12, 13, 20, 22, 27–29]

Tables 41 to 43 show electric-power, steam, and process water requirements per pound of product output for a number of established processes.

Table 41. Power Requirements for Various Processes

Process	*Kwhr per lb of product*	*Process*	*Kwhr per lb of product*
Acetic acid from acetylene	0.210	Aluminum	9.000
Acetic acid from wood	0.037	Aluminum sulfate	0.015
Alumina from bauxite	0.090	Ammonia	0.750
		Ammonium chloride	0.085

Table 41. Power Requirements for Various Processes (*Continued*)

Process	*Kwhr per lb of product*
Ammonium phosphate	0.007
Ammonium sulfate	0.014
Ascorbic acid	4.100
Benzene hexachloride	0.620
Boric acid	0.025
Butadiene from alcohol	0.055
Calcium carbide	1.700
Calcium cyanamide	1.600
Carbon bisulfide	0.450
Cement, portland	0.050
Chloroquine	2.200
Copper, electrolytic	1.200
Cornstarch	0.050
Coumarin	0.450
Dry ice	0.156
Ethanol from molasses	0.017
Ethanol, synthetic	0.300
Ethylene glycol from chlorohydrin	0.080
Ethylene oxide	0.070
Ferric chloride	0.004
Fluorine, electrolytic	2.900
Formaldehyde, 37%	0.030
Gasoline, catalytic	0.001
Gasoline, polymer	0.001
Glycerine	0.005
Graphite	1.700
Hydrochloric acid from salt	0.043
Hydrochloric acid, synthetic	0.002
Hydrogen from steam and iron	0.400
Hydrogen from water gas	0.600
Hydrogen peroxide	8.000
Hydrofluoric acid	0.140
Kraft pulp	0.170
Lactose	0.170
Lithopone	0.050
Manganese, electrolytic	5.100
Magnesium, electrolytic	8.000
Magnesium hydroxide, sea water and dolomite	0.015
Nitric acid	0.190
Nitroglycerine	0.043
Oxygen, liquid	0.930
Oxygen, tonnage	0.220
Phenol	0.130
Phosphoric acid, Dorr	0.052
Phosphoric acid, electric furnace	1.900
Rayon	2.600
Silica gel	0.030
Silicon carbide	4.200
Soda ash	0.048
Sodium	4.900
Sodium chlorate	2.700
Sodium hydroxide, lime-soda	0.044
Sodium hydroxide and chlorine, salt electrolysis	0.750
Sugar, beet	0.060
Sugar, cane	0.015
Sulfite pulp	0.230
Sulfur dioxide, liquid	0.002
Sulfuric acid	0.015
Superphosphate	0.011
Trisodium phosphate	0.040
Urea	0.170
Zinc, electrolytic	1.700
Zinc oxide	0.180

Table 42. Steam Requirements for Various Processes

Process	Lb per lb of product	Process	Lb per lb of product
Acetic acid from acetylene	3.1	Glycerine from soap	4.0
Acetic acid from wood, Othmer	2.8	Hydrofluoric acid	0.5
Acetic acid from wood, Suida	35.0	Hydrogen peroxide	9.0
Alumina	7.0	Kraft pulp	4.2
Aluminum sulfate	3.4	Lactose	40.0
Ammonium chloride	2.7	Nitric acid	0.3
Ammonium nitrate	1.5	Nitroglycerine	1.8
Ammonium sulfate	0.2	Oxygen, tonnage	2.2
Ascorbic acid	240.0	Phenolic resin	0.3
Benzene hexachloride	14.0	Phosphoric acid, Dorr	0.7
Boric acid	2.2	Rayon	70.0
Butadiene from alcohol	22.0	Silica gel	14.0
Calcium hypochlorite	3.3	Sulfite pulp	3.5
Casein	12.0	Sulfur dioxide, liquid	3.3
Cornstarch	1.5	Sulfuric acid, contact	0.1
Dry ice	8.5	Soda ash	2.0
Ethanol from molasses	6.1	Sodium	5.1
Ethanol, synthetic	3.0	Sodium bichromate	3.0
Ethylene glycol from chlorohydrin	12.0	Sodium chlorate	5.4
Ethylene oxide	11.0	Sodium hydroxide, lime-soda	1.4
Formaldehyde, 37%	2.2	Sodium silicate	0.5
Gasoline, catalytic	0.1	Sugar, beet	5.7
Gasoline, polymer	0.4	Sugar, cane	1.6
		Trisodium phosphate	0.1
		Vanillin	16.0

Table 43. Process Water Requirements for Various Processes

Process	Gal per lb of product	Process	Gal per lb of product
Acetic acid from acetylene	43.0	Hydrochloric acid from salt	1.5
Acetic acid from wood, Suida	120.0	Hydrochloric acid, synthetic	0.3
Alumina	3.2	Hydrofluoric acid	43.0
Aluminum sulfate	0.5	Hydrogen from steam and iron	190.0
Ammonia	47.0	Hydrogen from water gas	370.0
Ammonium nitrate	1.2	Kraft pulp	25.0
Ammonium sulfate	2.5	Lactose	100.0
Ascorbic acid	870.0	Magnesium hydroxide, sea water and dolomite	0.2
Boric acid	0.1	Nitroglycerine	0.7
Butadiene from alcohol	190.0	Oxygen, liquid	21.0
Calcium carbide	16.0	Oxygen, tonnage	13.0
Calcium hypochlorite	27.0	Phenolic resin	0.7
Cellulose nitrate	50.0	Phosphoric acid, Dorr	7.3
Cement, portland	0.3	Rayon	170.0
Cornstarch	0.3	Silica gel	10.0
Dry ice	9.0	Sodium	37.0
Ethanol from grain	2.5	Sodium chlorate	30.0
Ethanol from molasses	8.0	Sodium hydroxide, lime-soda	1.1
Ethanol, synthetic	37.0	Sulfite pulp	30.0
Ethylene glycol from chlorohydrin	40.0	Sulfur dioxide, liquid	9.0
Ethylene oxide	37.0	Sulfuric acid, chamber	1.2
Formaldehyde, 37%	23.0	Sulfuric acid, contact	2.2
Gasoline, catalytic	1.2		
Gasoline, natural	3.6		
Gasoline, polymer	6.0		
GRS copolymer	310.0		

Table 44. Utility Rates

Type of utility	*Rate*
Steam:	
400 psi	$0.50–$0.90/1,000 lb
100 psi	0.25–0.70/1,000 lb
Exhaust	0.15–0.30/1,000 lb
Electric power:	
Purchased	0.01–0.02/kwhr
Self-generated	0.005–0.01/kwhr
Cooling water:	
Well	0.02–0.10/1,000 gal
River or salt	0.01–0.04/1,000 gal
Tower	0.01–0.05/1,000 gal
Process water:	
City	0.07–0.25/1,000 gal
Well	0.02–0.10/1,000 gal
Filtered and softened	0.10–0.20/1,000 gal
Distilled	0.60–1.00/1,000 gal
Compressed air:	
Process air	0.015–0.03/1,000 cu ft
Filtered and dried for instruments	0.04–0.10/1,000 cu ft
Coal	6.00–10.00/ton
Fuel oil, No. 6	0.04–0.08/gal
Gas:	
Natural	0.30–0.80/1,000 cu ft
Manufactured	0.60–1.30/1,000 cu ft
Refrigeration:	
Steam-jet, 50°F	0.55/ton day
Ammonia, 34°F	0.50/ton day
Ammonia, 0°F	0.90/ton day
Ammonia, −17°F	1.20/ton day

Utilities may be supplied in any one of the following three fashions, with charges made accordingly:

1. The service may be purchased from a public utility at the established rate.

2. The utility may be provided by a central station supplying the entire plant at a rate based upon the operating cost of the service installation.
3. The service may be self-generated but used by only one process. The service installation may be included as a part of the fixed-capital cost of the production unit and the operating expenses of the utility charged directly to the manufacturing cost.

Since the cost of services may vary to a considerable extent, the estimator should check the established rates in the community in which the plant is located. In general, the values listed in Table 44 should suffice for most purposes. Since these figures represent ranges of cost, it will be noted that some overlapping occurs.

INDIRECT COST

The indirect costs are those expenditures which are incurred as a result of, but not directly by, the productive operation. The line of distinction between direct and indirect manufacturing cost is sometimes quite arbitrary. Therefore, some variance in classification will be found to exist.

Payroll Overhead

All company expense incurred through pensions, paid vacations, group insurance, disability pay, social security, and unemployment taxes is classified as payroll overhead. While each of these items may be estimated individually, they may be estimated in total as being an amount equivalent to 15 to 20 per cent of the labor cost.[10, 12, 22, 23, 34]

Laboratory

In chemical processing, laboratory work is required to ensure quality control. While this expense will of course depend upon the type of product, an average cost equivalent to 10 to 20 per cent of the labor cost may be employed. A value of $5 per man-hour including overhead may be employed to approximate laboratory work.[10, 12, 22]

Plant Overhead

Plant overhead is the cost of maintaining certain service functions required indirectly by the productive unit. It includes such costs as maintaining medical and recreational facilities, purchasing, warehousing, and engineering. Generally these charges are collected in total and distributed over productive operations in direct proportion to labor. A value equivalent to 50 to 100 per cent of the productive-labor cost may be applied in estimating indirect production cost. Plant overhead, in proportion to labor, will be higher for plants composed of complex operations than for plants employing simple procedures. Similarly, small factories will usually have a higher proportion of plant overhead to direct labor than large ones.[10, 12, 22, 23, 34]

Packaging

The cost of containers for packaging depends largely upon the chemical and physical nature of the product as well as on its value. Figure 83 shows the purchased cost of various types of containers as a function of capacity.[6, 12, 22, 23, 35, 41]

Many chemicals are shipped in bulk in special freight cars. Tank cars are generally of 4,000 to 8,000 gal capacity; hopper cars vary from 1,300 to 3,000 cu ft of carrying volume. Rental charges on such cars are listed in Table 45. It is important

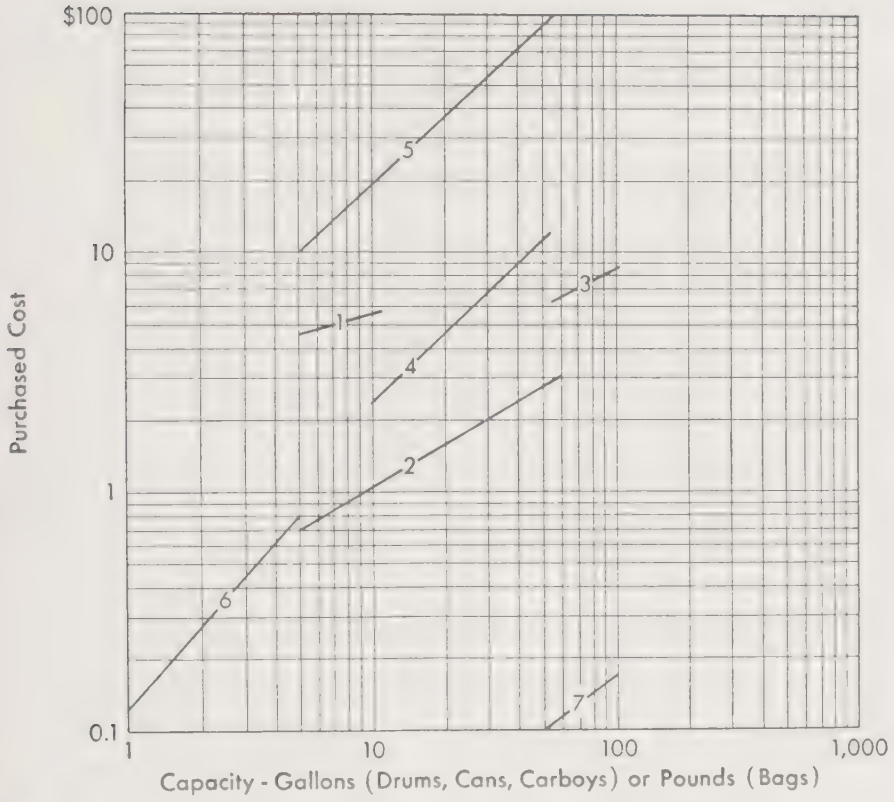


Fig. 83. Containers. (1) Glass carboys, (2) fiber drums, (3) steel drums (general use), (4) steel drums (heavy duty), (5) stainless-steel drums, (6) steel cans, (7) paper bags (product density equals 50 lb per cu ft).

to realize that the use of these rented cars results in a rebate from the railroads upon shipment: these allowances amount to \$0.03 per car-mile on tank cars and \$0.032 per car-mile on hopper cars.

Table 45. Railroad-car Rentals

Type of car	*Rental per month*
Chlorine tank car	\$150
Sulfuric acid tank car	65
Rubber-lined tank car	75
Steel tank car	50
Stainless-steel tank car	250
Aluminum tank car	200
Covered-hopper car	120

In addition to the price of containers, the approximate cost of packaging and handling for carload shipment is shown in Table 46 for various sizes of containers.

Table 46. Packaging and Handling Cost for Carload Shipment

Container	*Unit cost*
For liquid product:	
Tank car	\$0.005/gal
55-gal drum	0.04/gal
5-gal can	0.08/gal
1-gal can	0.10/gal
For solid product:	
Hopper car	0.0015/lb
100-lb bag	0.005/lb
50-lb bag	0.009/lb

Only a small portion of the chemical industry's products are prepared for direct sale to the ultimate consumer. Table 47

indicates the important part which total packaging expense can play in industries preparing their products for the ultimate consumer. Total packaging expense is shown in this table as a percentage of the manufacturer's sale price.

Table 47. Total Packaging Expense as Percentage of Manufacturer's Sale Price

Product	*Total packaging expense, %*
Pharmaceuticals	35
Hardware and small parts	4
Confectionary	21
Paints and waxes	13
Cosmetics and soaps	36
Food products	24
Inks and adhesives	40
Oil products	35

Shipping

Many chemical products are sold on an F.O.B. basis, and thus the cost of shipping does not need consideration. If, however, the product is to be sold on a delivered basis, shipping charges must be evaluated.[23, 30-33]

The basic railroad rate structures are the class rates, which are generally the highest tariffs applicable. These are a series of rates on a mileage basis, with the 100 per cent level known as the first-class rate. Lower tariffs are related to the first-class rate on a percentage basis. In order to assign the proper rate, a freight classification must be employed to ascertain the proper class for the transported material. Figure 84 shows an approximation of the first-class scale which may be employed for estimating purposes.

The vast majority of the carload freight movement in this country is shipped under commodity or exception rates. These

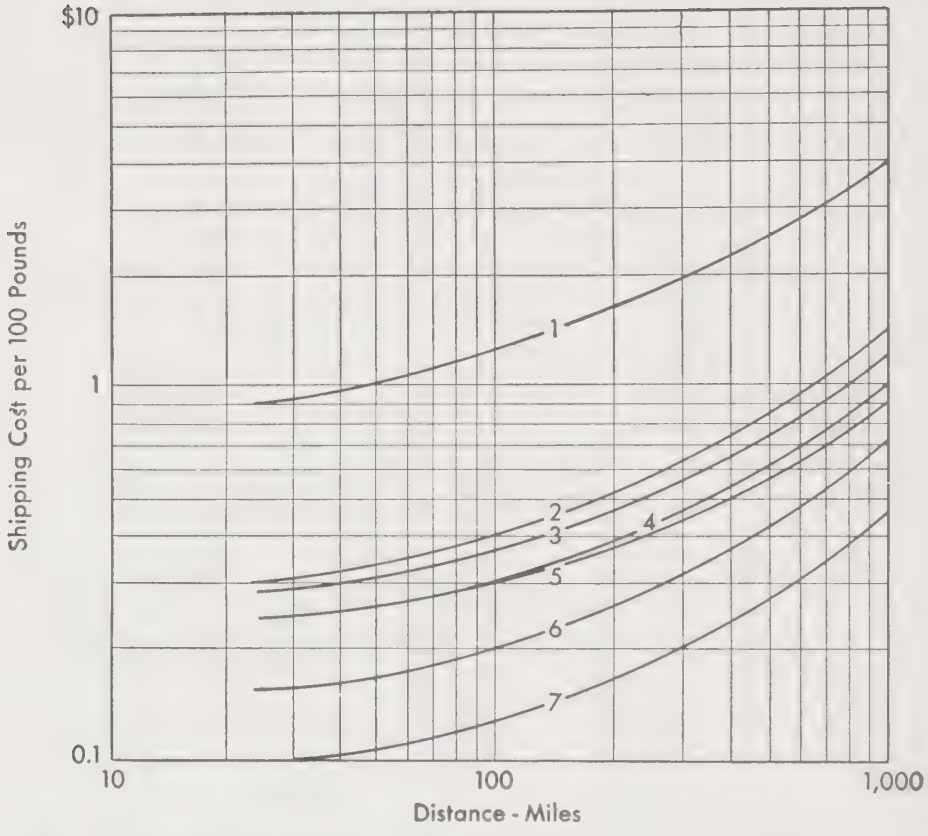


Fig. 84. Railroad shipping rates. *Class rates:* (1) first class. *Commodity and exception rates (carloads):* (2) Anhydrous ammonia, liquid chlorine, denatured ethanol, (3) benzene, (4) fuel oil, (5) sulfuric acid, (6) soda ash, caustic soda, (7) coal.

rates, which are lower than the class rates, are established when conditions encompassing the particular movement of a commodity are deemed abnormal under class-rate standards. Figure 84 presents a generalized indication of commodity rates on several different materials. The evolution of rates is extremely complex. The factors leading to their determination are as follows: value, density, perishability, potential destructiveness, quality of being essential to the public welfare, and service rendered to the consignor and consignee.

The use of trucks over short hauls will generally prove to be less expensive than railroads. Even over long distances truck rates have become closely competitive with rail tariffs. Water transportation over inland waterways or coastal routes employing barges or tankers may be estimated at $5 per ton per 1,000 miles.

FIXED COST

Fixed costs are those charges reflecting the initial fixed-capital investment and associated expenses which remain constant in total with regard to time, regardless of production level.

Depreciation

In order to go into a new productive venture a fixed-capital expenditure must be made for equipment and buildings. Depreciation may be called the attempt to write off such a capital expense over what is regarded as the unit's productive life, after which it is considered as having only salvage value. According to the Internal Revenue Code, depreciation is defined as "a reasonable allowance for exhaustion, wear and tear on property used in the trade or business, including a reasonable allowance for obsolescence." [7] Present normal depreciation rates do not impart sufficient emphasis to the obsolescence factor.[7, 10, 12, 15, 17, 19, 23, 34, 36]

For estimating purposes total annual depreciation may be estimated as equivalent to 8 to 10 per cent of the fixed-capital investment. In some cases emergency plant facilities, built in the last several years in association with the national defense effort, have been allowed accelerated write-offs with rates as high as 20 per cent per year with governmental approval.

Tables 48 and 49 show the estimated average lives of various types of equipment and plants, respectively.

Table 48. Estimated Average Life of Equipment

Equipment	*Years*	*Equipment*	*Years*
Boilers	25	Gas furnaces	8
Buildings		Grinders	12
Brick and steel	33	Kettles	6
Concrete block	5	Kilns	22
Steel frame, corrugated-iron walls	12	Mills	12
Columns	8	Mixers	12
Compressors	20	Motors	14
Condensers	17	Pipes	15
Coolers	17	Pumps	20
Crushers	12	Retorts	22
Digesters	10	Screens	12
Dryers	25	Sifters	12
Electric furnaces	20	Stills	17
Evaporators	17	Tanks	20
Filter presses	17	Thickeners	5
		Transformers	15

Table 49. Average Life by Plant

Type of plant	*Years*	*Type of plant*	*Years*
Acids	15	Electrochemical	17
Alkaline products	22	Oxygen production	18
Aniline dyes	20	Pharmaceutical	20
Atmospheric nitrogen	15	Pulp	17
Carbide and carbon products	15	Refinery	25
Coal-tar products	21	Soap	20

Property Taxes

Property taxes are completely dependent upon the locality in which the plant is situated. In general, plants located in cities pay higher taxes than those in less populated regions. However, even cities show wide variation in tax rates and assessed valuation. Many times governing authorities will offer concessions in an effort to attract new enterprise.[12, 22, 23, 36, 42]

In the absence of specific data, such as those listed in Table 50, an annual value equivalent to 1 to 2 per cent of the fixed-capital investment may be used to approximate property taxes.

Table 50. Real-estate Tax Rates

City	Rate per $100 valuation	Assessed valuation, %
Population 1,000,000 plus:		
New York	$ 2.89	
Chicago	2.87	100
Detroit	3.07	100
Los Angeles	2.99	50
Population 500,000–1,000,000:		
Boston	5.34	100
Pittsburgh	5.38	100
San Francisco	6.09	50
St. Louis	2.44	100
Cleveland	3.27	80
Population 250,000–500,000:		
Minneapolis	13.50	40
Atlanta	2.35	
Louisville	3.43	100

Insurance

Although a small expense, insurance rates on plants vary to a wide extent depending upon hazards involved. A figure for

annual insurance equivalent to 1 per cent of the fixed-capital investment may be employed for estimating.[12, 22, 23, 36]

Equation for Manufacturing Cost

Total manufacturing cost may be approximated by the following equation:

$$M = m + u + h + 3.55k + \frac{0.21I_F}{r_a}$$

where M = manufacturing cost per unit of production
m = raw material cost per unit of production
u = utility cost per unit of production
k = man-hours of labor per unit of production
I_F = fixed-capital investment
r_a = annual production rate
h = container and shipping cost per unit of production

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5. GENERAL EXPENSE

The various expenditures incurred by company functions other than manufacturing are grouped into a classification called general expense. This covers the cost of administration, sales, research, and finance.[1, 6]

Table 51. General Expense Estimate

Administration	$_____
Sales	_____
Research	_____
Finance	_____
General Expense	$_____

Administration

The administrative expense of a company pertains to expenditures such as management salaries, legal fees, and auditing charges incurred in the over-all management of all phases of the company's enterprise. For estimating purposes administration costs may be determined as being an amount equivalent to 2 to 3 per cent of the sales price or 3 to 6 per cent of the manufacturing cost.[2, 3, 9, 15]

Sales

Sales expense will vary considerably depending upon type of product, method of selling and distribution, customer market, and extent of advertising. Because of the diversity of the

many factors affecting sales expense, it is difficult to assign a definite factor for estimating purposes. Sales expense may vary from 2 to 30 per cent of the sales price. The low range may be considered applicable to standardized products, requiring little promotional effort, which are sold principally in large volume to other manufacturers; the other extreme is representative of newly developed lines which require promotion for ultimate sale through distributors to the consumer in the manufactured form. In general, sales expense may be roughly estimated by the process of assigning to it an amount equal to 3 to 12 per cent of the sales price or 5 to 22 per cent of the manufacturing cost.[2, 3, 8, 9, 12, 15]

Research

The chemical industry spends 2.5 per cent of its sales dollar on research, compared to the over-all industrial average of 2 per cent. However, the average total cost of research per scientist or engineer is $17,000 per year for the chemical industry, whereas the average for all industry is $22,000. The difference is brought about by the employment of relatively few supporting workers in the chemical industry. It has been found that this figure varies directly with the size of the research staff. If research expense is based upon the number of scientists and engineers plus supporting personnel, the average

Table 52. Cost of Research as a Percentage of Sales

Product	*Research expense, %*
Pharmaceuticals	4.8
Industrial chemicals	2.8
Paints	1.7
Clay products and glass	1.2
Metals	0.9
Rubber	0.9
Paper and wood products	0.7
Petroleum and coal products	0.7

cost is $9,000 annually; however, little fluctuation occurs in this value for different types of industries and sizes of research staffs. For estimating purposes, research expense may be approximated as being equivalent to 2 to 4 per cent of sales price or 3.5 to 8 per cent of manufacturing cost.[3, 7, 9, 13, 14]

Finance

Until the last few years, chemical expansion was generally financed from retained earnings. With the advent of confiscatory income-tax rates, retained earnings became generally insufficient for the industry's rapid expansion pattern, and other sources of capital had to be sought. While borrowed capital is only one of the alternative means, it is the only one on which the carrying expense can be included as an item of cost for income-tax purposes. Other returns on capital, such as dividends on preferred or common stock, are payable after income taxes.[4–6, 8, 10, 11]

Interest on borrowed capital may be estimated at 2 to 4 per cent annually. It is important to note that it is considered incorrect to classify interest as a fixed manufacturing cost, although this practice is sometimes followed in evaluation studies.

Equation for General Expense

General expenses may be quickly approximated by use of either of the following two equations:

$$G = 0.13S + \frac{0.03B}{r_a}$$

$$G = 0.22M + \frac{0.03B}{r_a}$$

where G = general expenses per unit of production
S = sales price per unit of production
M = manufacturing cost per unit of production
B = amount of outstanding borrowed capital
r_a = annual production rate

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6. SALES AND PROFITS

THE last two chapters have been devoted to the cost of making a product available to the market. This chapter will deal with the proceeds achieved through sales to the market and the profits or return over expenditures made as a result of sales.[2]

Table 53. Profit Estimate

Sales		$_____
Manufacturing cost	$_____	
General expense	_____	
Total cost		_____
Profit before taxes		$_____
Income taxes		_____
Profit after taxes		$_____

Sales

For estimating purposes, sales may be thought of as the marketable value of a company's production. Deducting allowances for contract or bulk purchases, the net sales can be calculated. Discounts need not be considered unless they are known to represent an established portion of a plant's output. Generally speaking, sales prices are almost double manufacturing expenses.[1, 5, 11, 16]

Selection of a sales price may be a simple or a complicated matter. Its complexity is sometimes furthered by external factors having no direct bearing upon the product's salability.

If the product is already being manufactured by competitors, the price may be set at or below competitive values. If the commodity is new but its utilization lies in fields being supplied satisfactorily by established materials, the price may be determined by comparison of competitive product performance. Table 33 may prove useful in both of these cases.

Fortunately most pricing problems will meet one of these two criteria. However, if neither of these situations exists and there is nothing upon which to base a sales price, the method of price establishment is completely altered. In such a case, the desired profit is added to the total cost of a product to determine a sales price. Such a profit margin may be a fixed percentage of the sales price or cost, or may be based upon a desired return on the investment.

Profit

Profit may be defined as the excess of income over expenditure. There are two types of profit for the estimator to consider—profit before income taxes and profit after income taxes. The former is calculated by deducting both the manufacturing cost and general expenses from the sales revenue. Profit after income taxes is simply the before-tax profit reduced by income taxes.[5, 10, 16]

Federal income-tax rates are subject to periodic revision and should be checked to ensure the validity of the rate employed. A revision in the tax structure made in 1954 extended the base rate for corporations at 52 per cent of profit.

State taxes, although of relatively minor consequence in comparison with Federal taxes, should also be considered. In the absence of exact rates, a 3 to 5 per cent tax on the profit before tax may be levied.

Some estimators prefer to determine the profitability of a

venture by considering only the profit before income taxes. Their reasoning is based on the fact that tax rates are a factor over which the company can exercise no control. Furthermore, in a comparison of several proposed ventures, all will suffer when income-tax factors are introduced: thus the same relative order of profitability will exist. While both of these points are correct, it should be remembered that the only reason for undertaking a venture is to earn a real profit. Since the latter can be determined only by deducting taxes, the consideration of Federal and state income taxes seems to be a more realistic approach.

Equation of Profit

Profits before and after taxes may be approximated by the following equations:

$$P_b = S - M - G$$

$$P_a = 0.44(S - M - G)$$

where P_b = profit before taxes, per unit of production
P_a = profit after taxes, per unit of production
S = sales price per unit of production
M = manufacturing cost per unit of production
G = general expenses per unit of production

METHODS OF EXPRESSING PROFITABILITY

There are several basic methods of quantitatively expressing the relative attractiveness of new ventures. Often one means will suffice while in other instances more than one expression will be required for adequate conclusion of a study. Generally, it is strictly a matter of management preferring one type to another for use in project evaluation. In the subsequent paragraphs, the basic measures are explained in their simplest form.

Per Cent Profit on Sales

One of the simplest expressions for profitability measure is the per cent profit on sales. This is simply the unit profit, either before or after taxes, as desired, expressed as a percentage of the unit sales price. Profitability is thus expressed in terms of the margin between cost and sales price. While the method is simple in preparation, its prime shortcoming is that it fails to indicate, in comparing several products, the investment required for producing each. Below is the expression in equation form for the per cent profit on sales determination.

$$P_{sb} = \frac{P_b}{S}$$

$$P_{sa} = \frac{P_a}{S}$$

where P_{sb} = per cent profit on sales before taxes, expressed as a decimal
P_{sa} = per cent profit on sales after taxes, expressed as a decimal
S = sales price per unit of production
P_b = profit before taxes per unit of production
P_a = profit after taxes per unit of production

Per Cent Return on Investment

One of the most common ways of relating profitability on new ventures employs what is known as the per cent return on the investment, which is the annual rate at which profits will return the investment. In its basic form it may be defined as the ratio, expressed as a percentage, of the annual profits to the capital investment. Profits may be on a before- or after-tax basis, as desired. The advantage of this method lies in the fact that profitability is expressed in terms of the investment required to undertake the venture. While the subsequent expressions employ fixed capital only, it is considered equally

correct to apply both fixed- and working-capital requirements.[7, 9]

$$P_{rb} = \frac{P_b r_a}{I_F}$$

$$P_{ra} = \frac{P_a r_a}{I_F}$$

where P_{rb} = per cent return on investment before taxes, expressed as a decimal
P_{ra} = per cent return on investment after taxes, expressed as a decimal
r_a = annual production rate
P_b = profit before taxes per unit of production
P_a = profit after taxes per unit of production
I_F = fixed-capital investment

The rate of anticipated return on the capital investment should vary directly with the degree of risk or the probability of failure involved. Table 54 relates the minimum acceptable

Table 54. Minimum Acceptable Return on Fixed-capital Investment

Industry	Minimum acceptable return before taxes, %	
	Low risk	High risk
Industrial chemicals	11	44
Petroleum	16	39
Pulp and paper	18	40
Pharmaceuticals	24	56
Metals	8	24
Paints	21	44
Fermentation products	10	49

per cent return before taxes for various types of industrial enterprise at both high and low risk.

The higher values for acceptable return will apply to new, untried ventures, where extrapolation to plant scale is large and market conditions are uncertain. Conversely, the lower values will apply to established propositions already on a commercial scale. After determination of the risk factor, the minimum acceptable rate of return on the investment can be selected from the table. This may be converted to an after-tax basis by multiplying by the quantity 1 minus the income-tax rate expressed as a decimal. In addition to its use as a comparison measure, Table 54 may be employed for calculation of a minimum sales price on a product as described in Chap. 5.

$$S = \frac{I_F P_k}{r_a} + M + G$$

where S = sales price per unit of production
I_F = fixed-capital investment
P_k = minimum acceptable per cent return on investment before taxes, expressed as a decimal
M = manufacturing cost per unit of production
G = general expenses per unit of production
r_a = annual production rate

Venture Profitability

Quantitatively speaking, venture profit may be defined as the excess of the calculated profit over the minimum acceptable amount. Thus, by employing the minimum acceptable values as listed in Table 54, the venture profit before taxes may be determined from the following equation: [4, 7, 12, 15]

$$V = P_b - \frac{I_F P_k}{r_a}$$

where V = venture profit per unit of production
P_b = profit before taxes per unit of production

P_k = minimum acceptable per cent return on investment before taxes, expressed as a decimal
I_F = fixed-capital investment
r_a = annual production rate

The above expression may also be calculated on an after-tax basis.

The annual venture profit expressed as a percentage of capital investment is a method of showing the additional gain to be expected over and above a minimum acceptable return for an investment of a given risk. It is a means of quantitatively comparing the financial attractiveness of endeavors having entirely different risks.

Pay-out Time

A widely used method of evaluation is pay-out time. In its basic and most applicable form it may be defined as the number of years in which the capital investment will be returned by the profits calculated before deducting depreciation. It thus shows the number of years that will elapse before any earnings over the initial investment will be realized.[3, 6–8, 13, 14]

$$D = \frac{I_F}{P_b r_a + 0.1 I_F}$$

where D = pay-out time in years
P_b = profit before taxes per unit of production
r_a = annual production rate
I_F = fixed-capital investment

The above expression is based upon a before-tax position; if an after-tax pay-out time is desired, D should be divided by 1 minus the income-tax rate, expressed as a decimal.

Shown in Table 55 are maximum acceptable pay-out times for various fields at high and low risk.

Table 55. Maximum Acceptable Pay-out Time

Industry	Maximum acceptable pay-out time before taxes, years	
	Low risk	High risk
Industrial chemicals	5	2
Petroleum	4	2
Pulp and paper	4	2
Pharmaceuticals	3	2
Metals	6	3
Paints	3	2
Fermentation products	5	2

Cash Position

Whereas per cent return shows the earning rate of an investment and pay-out time notes the time at which the investment will be completely returned by profits, cash position reflects the total assets after retirement of the investment. Thus the income is used first to retire the investment and then to accumulate a cash reserve. This method's primary advantage is that it shows the absolute profit in dollars at any given time rather than in the relative terms employed for per cent return and pay-out time. The cash position after taxes at any time up to the assumed full 10-year depreciation period is reflected by Eq. (1) below; for any period of time after the 10-year interval, cash position is shown by use of Eq. (2).[7]

$$H = (P_b r_a + 0.1 I_F - P_b r_a t) d - I_F \qquad (1)$$

$$H = (P_b r_a + 0.1 I_F - P_b r_a t) 10 - I_F + (P_b r_a + 0.1 I_F)(1 - t)(d - 10) \qquad (2)$$

where H = cash position

P_b = unit profit before taxes

r_a = annual production rate

I_F = fixed-capital investment

t = income-tax rate, expressed as a decimal

d = number of years at which cash position is measured

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7. THE EFFECT OF VARIABLE CONDITIONS UPON COSTS AND PROFITS

The previous chapters have dealt with costs and profits under static conditions. In other words the values were calculated at a specified volume of production for a plant of a certain design capacity. It is often important to ascertain the effect upon costs and profits of two basic types of variable conditions: capacity output of various-sized installations and less-than-capacity operation of a specified plant. By extrapolating from values of sales, investment, cost, and profit calculated under fixed conditions, it is possible to determine what may reasonably be expected to occur under changing conditions. While the approximations to be discussed will reduce the precision of the individual results, they are fully adequate to indicate trends.

VARIATION OF PLANT SIZE

Analysis of variation of plant size is most often required to indicate the correct level to which to build a plant. Capacity selection should always be based upon maximum profitability. To do this the variation of sales price, investment, and cost must be calculated over the entire range of contemplated operation.[7, 9, 10]

Sales

It is quite possible that no variation of sales price with annual output will occur over the range of contemplated operation. However, it is important that due consideration be given to this factor. Should such a variation be apparent, a market study will be required to indicate the company's share of the total market, considered by consumer groups, at various sales prices.

Investment

Chemical plants achieve higher capacity through the use of larger individual units as well as through the use of more small pieces of equipment. The investment varies approximately as the 0.6 power of the capacity for that portion of the plant which increases its capacity by employing larger equipment. The investment will vary directly with the capacity for that portion which is increased in capacity by using multiple units. By analyzing the plant in this manner, the variation of investment with capacity may be ascertained. For most chemical-process plants, the investment has been shown to vary as the 0.7 power of the capacity.

Cost

The many components of manufacturing cost and general expense may be analyzed for their variation with plant capacity. These variations may be best shown as logarithmic functions. Total expenditures for raw materials, utilities, shipping, packaging, and royalties have been found to change in direct proportion to the capacity, and thus will be essentially constant per unit of output. Fixed manufacturing costs, maintenance, and plant supplies tend to vary as the same power of the capacity as investment. (See above.) Labor has demonstrated a variance as the 0.25 power of the capacity for plants attaining higher output through the use of larger sizes of equipment; on operations consisting of equipment multiples,

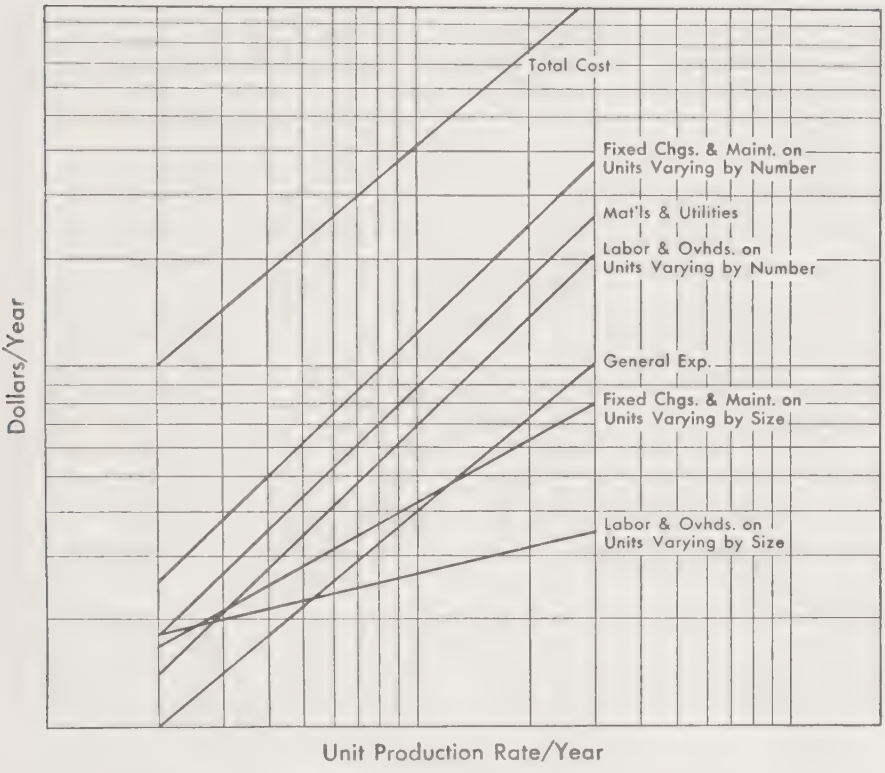

Total Cost
Fixed Chgs. & Maint. on Units Varying by Number
Mat'ls & Utilities
Labor & Ovhds. on Units Varying by Number
General Exp.
Fixed Chgs. & Maint. on Units Varying by Size
Labor & Ovhds. on Units Varying by Size
Dollars/Year
Unit Production Rate/Year

Fig. 85. Variation of plant size: cost.

the labor force will increase in nearly direct proportion to the capacity, as long as the manpower is fully utilized. Items such as supervision, laboratory, and overhead are proportional to labor. General expense will be found to vary directly with the manufacturing cost over the range of volume.

By analyzing each element of cost and combining these elements into groupings which demonstrate a particular mathematical variation, the relationship between cost and capacity can be derived. The resultant data can be plotted in the form demonstrated in Fig. 85.

Profit

The difference between the unit sales price and the unit cost will give the unit profit, which may be calculated on either a before- or an after-tax basis, whichever is preferred. In cases where a variation in sales price as well as cost is revealed, the unit profit will not necessarily reach a maximum at the same point of output indicated for minimum cost.

Maximum unit profit, however, cannot be employed as a measure of plant-size selection. By multiplying the maximum unit profit by the yearly output, the annual profit may be ascertained and plotted as a function of capacity. The capacity indicating maximum annual profit will not coincide in all likelihood with that for maximum unit profit, as shown by Fig. 86.

By expressing the annual profit as a percentage of the investment at corresponding capacity levels, a curve of per cent return on investment as a function of output can be developed. Such a graph may show that the point of production where maximum per cent return lies is not the point of maximum annual profit. Whether a plant should be expanded to a point where maximum per cent return on the investment or maximum annual profit is earned is a question which must be answered by management to fit the particular product and situation. While it is recognized that the problem has many facets, it may be resolved generally around one focal point.

First of all, no level of production should be considered which fails to reach a prescribed minimum per cent return on the investment, one commensurate with the risk involved. If the per cent return is deemed to be satisfactory at the level of annual output which shows the maximum annual profit, then the expansion should be made to the level of maximum annual

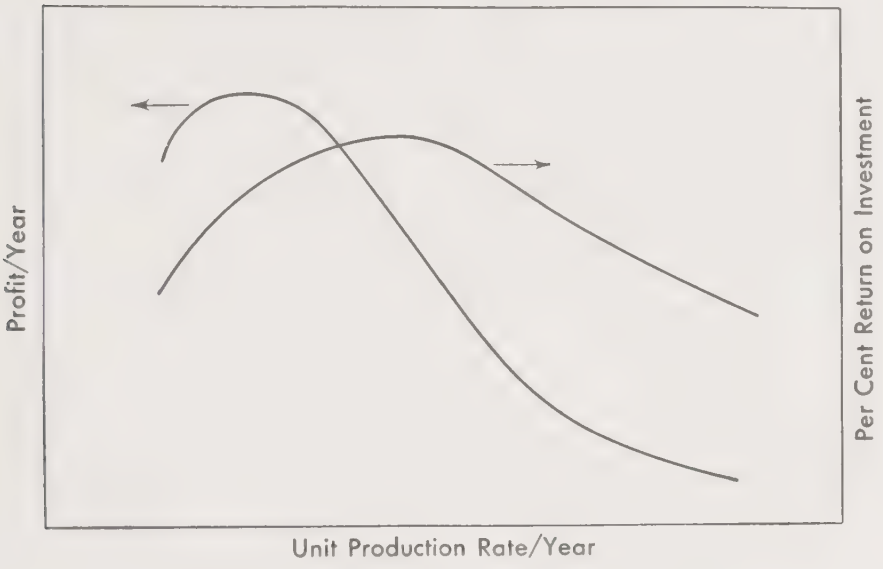


Fig. 86. Variation of plant size: profit.

profit, provided that the per cent return at such an output exceeds the per cent return, commensurate with the risk, for any other possible investment which could be made. Otherwise the capacity shown for maximum per cent return should be selected.

VARIATION OF PRODUCTION RATE

The effect upon costs and profits due to operation at less than the full capacity potential of a plant can be illustrated graphically. Basically speaking, this type of graph is called a break-even chart. Such a chart is simply a plot of costs, sales, and profits as functions of production level for a plant of speci-

fied capacity. The horizontal coordinate of a break-even chart designates the number of production units manufactured annually, from zero to maximum design capacity. The vertical coordinate represents the annual dollar value of costs, sales, and profits.[1–6, 8, 9]

Cost

Before a chart can be constructed, the components of the total unit cost must be calculated at annual maximum capacity. Each of the components of annual expense must then be segregated into the following three types of cost reflecting the mathematical variation with production level for a particular size of plant.

1. Fixed costs, which are constant at all production levels.

   Depreciation.
   Taxes.
   Insurance.

2. Variable costs, which are directly proportional to production level.

   Raw materials.
   Packaging containers.
   Utilities.
   Shipping.
   Royalties.

3. Regulated costs, which are somewhat proportional to production level.

   Labor.
   Overhead.
   Supervision.
   Laboratory.
   General expenses.
   Maintenance.
   Plant supplies.

Each of these three classifications is totaled. The fixed expenses are then plotted at full capacity, as shown in Fig. 87; inasmuch as such costs do not vary with production, the same value will prevail at all levels. The variable expenses are then graphed at maximum capacity above the fixed costs; since variable expenses are directly proportional to output, they will

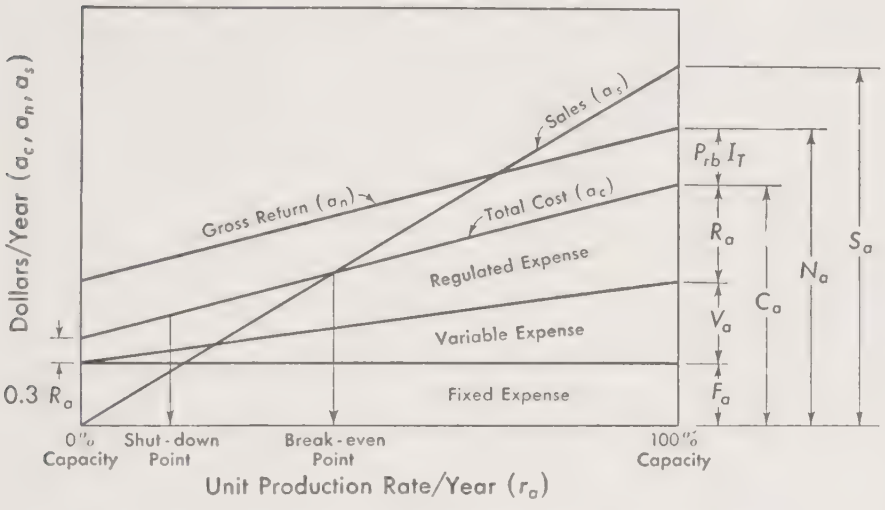


Fig. 87. Variation of production rate, annual basis.

have no value at zero production. Regulated expenses for maximum capacity are then added to the fixed and variable charges; experience within the chemical industry has demonstrated that regulated expenses to initiate production will run about 30 per cent of the total value at maximum plant capacity and, therefore, such a value is employed at zero output. A line connecting the sums of these three expense categories at zero and maximum production represents the total annual cost. It may be represented by the following equation:

$$a_c = \frac{V_a + 0.7R_a}{\sim} r_a + F_a + 0.3R_a$$

where a_c = annual total cost at r_a
V_a = annual variable expense at maximum production
R_a = annual regulated expense at maximum production
F_a = annual fixed expense at maximum production
r_a = annual production rate
$\mathcal{Z}$ = annual maximum production

Sales

Total annual sales at maximum production may then be superimposed on the plot. Sales are of course proportional to production and therefore will have no value at zero output. The sales line may be represented as follows:

$$a_s = \frac{S_a}{\mathcal{Z}} r_a$$

where S_a = annual sales value at maximum production
$\mathcal{Z}$ = annual maximum production
r_a = annual production rate
a_s = annual sales value at r_a.

Break-even Point

The point at which the sales and total-cost lines intersect is called the break-even point, which is simply the level of output at which sales will equal total cost. Operation at capacities less than this value will result in a loss; output at higher levels will result in a profit. The break-even point may be represented by the following relationship:

$$r_a = \frac{(F_a + 0.3R_a)\mathcal{Z}}{S_a - V_a - 0.7R_a}$$

where r_a = annual production rate
F_a = annual fixed expenses at maximum production
R_a = annual regulated expense at maximum production
S_a = annual sales value at maximum production
V_a = annual variable expense at maximum production
$\mathcal{Z}$ = annual maximum production

Shutdown Point

While the break-even point is the level below which no profits are earned, it is not the production level at which it becomes less expensive to close the plant and pay fixed expenses out of pocket rather than continue operations. Such a production level is called the shutdown point and is reached when output decreases to such a level below the break-even point that the fixed expenses are less than the difference between total cost and total sales. It may be illustrated by the following equation:

$$r_a = \frac{0.3R_a\mathcal{Z}}{S_a - V_a - 0.7R_a}$$

where r_a = annual production rate
R_a = annual regulated expense at maximum production
V_a = annual variable expense at maximum production
S_a = annual sales value at maximum production
$\mathcal{Z}$ = annual maximum production

Profit

It often becomes desirable to determine the effect of sales price and production rate upon the per cent return on the investment for a given plant size. Above the total cost at maximum capacity an amount is added which is equal to the annual profits before taxes required to achieve a desired per cent return on the investment. (An after-tax profit may be used if desired.) Employing this point, a line is drawn parallel to the total-cost line, as shown in Fig. 87. This line represents the total gross return from sales which must be maintained if the desired per cent return is to be maintained. This procedure may be repeated for several different values of per cent return.

An equation representing the gross sales return required to maintain the per cent return on investment follows.

$$a_n = \frac{V_a + 0.7R_a}{\mathcal{Z}} r_a + F_a + 0.3R_a + P_{rb}I_T$$

where a_n = annual gross return at r_a to maintain the per cent return on investment
V_a = annual variable expense at maximum production
R_a = annual regulated expense at maximum production
F_a = annual fixed expense at maximum production
$\mathcal{Z}$ = maximum production
r_a = annual production rate
I_T = total capital investment
P_{rb} = per cent return on investment before taxes, expressed as a decimal

This relationship can be equated to the one representing sales value. By rearranging, three different forms may be obtained:

1. The required unit sales price at a specified per cent return on investment and production rate.
2. The required annual production rate at a specified per cent return on investment and unit sales price.
3. The required per cent return on investment at a specified annual production rate and unit sales price.

$$\frac{S_a}{\mathcal{Z}} = \frac{V_a + 0.7R_a}{\mathcal{Z}} + \frac{F_a + 0.3R_a + P_{rb}I_T}{r_a} \tag{1}$$

$$r_a = \frac{(F_a + 0.3R_a + P_{rb}I_T)\mathcal{Z}}{(S_a/\mathcal{Z})\mathcal{Z} - V_a - 0.7R_a} \tag{2}$$

$$P_{rb} = \frac{(S_a/\mathcal{Z})\mathcal{Z} - V_a - 0.7R_a}{\mathcal{Z}I_T} r_a - \frac{F_a + 0.3R_a}{I_T} \tag{3}$$

where $\frac{S_a}{\mathcal{Z}}$ = unit sales price
r_a = annual production rate
P_{rb} = per cent return on investment before taxes, expressed as a decimal

V_a = annual variable expense at maximum production
R_a = annual regulated expense at maximum production
F_a = annual fixed expense at maximum production
$\tilde{\sim}$ = maximum annual production
I_T = total capital investment

Unit Basis

The previous discussion has shown how a break-even chart may be constructed and how various relationships and points of operation may be determined both graphically and mathe-

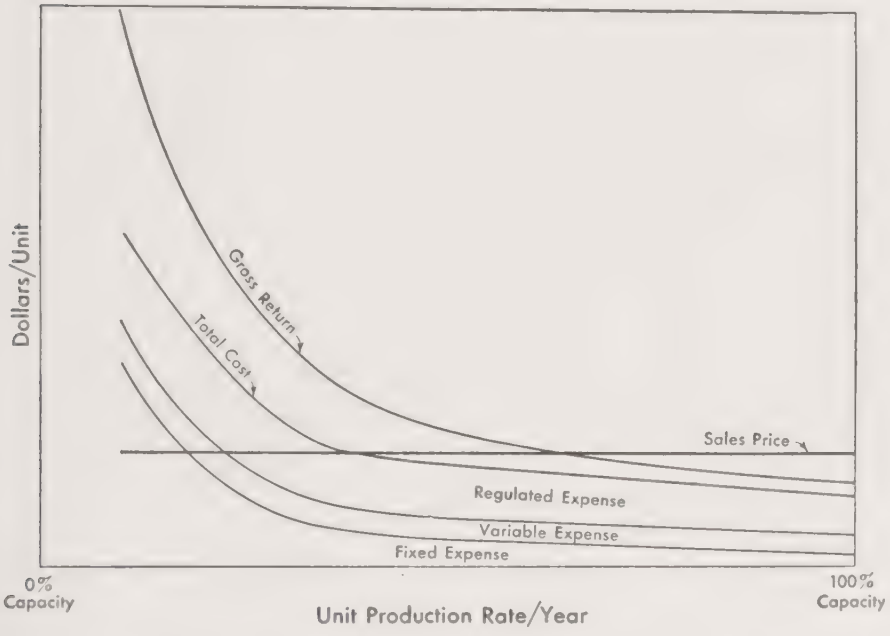


Fig. 88. Variation of production rate, unit basis.

matically. However, the monetary values revealed on a break-even chart are always for the total amount of annual output at the production rate in question. It is desirable to convert such values to a unit basis to show the effect on unit costs and profits of reduced-capacity operation of a given size of plant. This can be done by dividing the annual dollar value of any

point by the corresponding unit production rate, as shown in Fig. 88. A graph of this sort is useful in providing insight as to the economic limitations of a plant of a particular size.

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8. COST FACTORS IN PLANT LOCATION

THE aim of locating a new or a branch plant, or of relocating an existing unit, is to select the place which will enable a company to assemble materials, process them, and deliver the product to its customers at minimum cost. A thorough study must be made to analyze the relative importance of a firm's production and distribution requirements and the costs of meeting them at various possible sites.[1, 4, 7, 8, 10, 11]

Interrelationship of Cost and Location

The relative desirability of possible plant locations hinges upon two considerations: the cost or difficulty of carrying on the process itself at any given location and the cost or difficulty of bridging the distances between any given location and its sources of materials and markets. Thus the choice of a desirable location for any type of business is determined by weighing the relative advantages of possible sites in terms of difference in operating costs plus differences in the transfer costs that may be involved in collecting necessary materials and in marketing the product. In some operations, a single consideration may turn the balance, while in others the same factor may not apply at all.[3]

It should be remembered from the outset that cost alone is not the only or even at times the most important plant-location consideration. Besides company policies, many tangible and intangible items, such as type of community, recreational

facilities, and availability of financing, may become important. Even those plant-location factors to which costs can be assigned may require examination from the point of view of various intangibles. Thus, although labor rates may be established for estimating, labor costs will be significantly affected by such aspects as reliability of labor force, productivity, and absenteeism. In estimating costs for plant locations, such factors should not be neglected.

Selection of a spot for a manufacturing plant requires the careful weighing of a number of interrelated cost factors. Production and distribution costs involve consideration of the sources of materials, fuel, and power; prevailing wage rates and the efficiency of labor; transportation facilities and costs; and the nature, location, and extent of the market. Organizational factors can be important, especially as to the extent to which operations can be integrated with related processes. Sometimes the choice of a location may be influenced by inducements offered by local bodies or governments, for example, tax inducements.

A shift in the location of a plant (even though its original location may have been a historical accident) is likely to entail expenses through the sacrifice of much of the investment in the old site and building, a serious interruption to operations, loss of trained employees, and the moving of equipment and records. When inertia is added to these factors we can readily see why the offsetting advantages will have to be large to induce a move. Thus changes come mainly through the expansion of the industry in new and more favorable areas and the gradual decline of old centers.

A producer must often strike a balance of relative advantages in order to decide where best to locate. A simple case is a petroleum refinery or a cracking plant for chemicals. The producer uses oil and can locate, for example, either on the Gulf Coast where the oil sources are found, or in the East where the markets are centered. He can study the variation

of procurement cost and distribution cost for all possible sites in between. The best location gives the smallest total transfer costs. It may be found that the best place is the Gulf Coast, or the East may show some distinct advantages if cheap transportation for the oil by tanker is coupled with flexibility of production and distribution. No intermediary point will be found desirable in this case.

The engineer is thus confronted with two problems in a location study:

1. To determine several specific regions which would be economically desirable.
2. To make a detailed cost study of these locations and determine the most advantageous one.

Region Determination

The procedure employed in selecting specific regions for intensive location study is principally a negative mechanism. Its prime aim is to eliminate areas from consideration by successive exclusion.[6]

For example, locations unsuitable because of topography may be eliminated. From the remaining areas, one may remove those with inadequate access to transport facilities. Weather considerations may further prevent location in certain regions. Various other requirements can be imposed and the eligible areas further restricted on each examination until there emerges finally a map of the residual areas which have passed all test requirements. Such a method is in effect a rough method of preliminary zoning for industrial development. It does not remove the need for intensive studies of specific areas. By narrowing consideration to a small fraction of the total area, it should reduce the number of intensive surveys needed.

One preliminary method which may be used is that of *apparent association*. The engineer studies the usual pattern of the

industry and notes the dominant locational influences. For instance, if a certain type of chemical industry is usually found in the immediate proximity of oil refineries one might conclude without knowing anything further about the industry that nearness to oil refineries is the dominant locational requirement. Risks and limitations of such a method are evident.[5]

An important method of gauging the locational factors is to compute the relative magnitude of different items in the total cost of a product, as illustrated in Table 56. Such a tabula-

Table 56. Typical Product Cost

Cost item	*Percentage of total cost of product*
Materials and supplies	52.9
Labor	11.8
Payroll overhead, plant overhead, supervision	9.2
Utilities	6.6
Maintenance	4.2
Fixed cost	5.0
General expense	10.3
Total	100.0

tion can be useful as a basis for provisional elimination of unimportant factors and for further analysis of the important ones. However, it cannot stand by itself as a statement of relative weights of factors. In the alcoholic-beverage and tobacco industries, for example, a major cost item is the Federal tax; yet so far as choice of location within the United States is concerned, its influence is absolutely nil. A secondary defect of the breakdown of product cost is that it cannot be extended to cover the requirement of access to market. In view of the importance of sales costs, this is a grave defect and should be counterbalanced by careful market research.

Another method of measurement consists of gauging the importance of labor requirements, access to materials, and prod-

uct markets according to the amount spent on each. Thus, if an industry has an annual wage bill of $5,000,000, a freight bill of $2,500,000 on its materials, and selling expenses (including delivery expense on the product) of $7,500,000, the relative importance of labor costs, materials, and markets would be stated as 2, 1, and 3, respectively. This method will give somewhat different results from any of the previous ones. Its most serious defect is that it exaggerates the locational importance of transport costs on those materials which happen to be hauled long distances. It may well happen that the costs of transportation on the really dominant material (or product) show the least total expenditure, or none at all, simply because the plant has been so located as to minimize or eliminate these costs.

Locational Cost Study

Before choosing a site, production requirements should be stated in quantitative terms. In view of the possibilities of substitution of materials and adaptation of processes to local conditions, the statement of requirements may be rather complex, involving several different possible combinations. This may necessitate preliminary computations of costs using different processes. In the production of caustic soda, for example, in an area with cheap electric power, good access to sources of salt, and proximity to a market for chlorine, the basis of site selection would be the requirements of the electrolytic process. In certain other areas the requirements of the lime-soda process would govern. Similarly, in the production of phenol, the chlorination process is less costly than one involving the sulfonation of benzene, but the latter is preferable in localities where marketing of its by-products is economical. This versatility in processes and products contributes to competitive costs in plant locations.[9]

When the material and service requirements have been set up, with such flexible qualifications as may be appropriate,

the next step is to determine the capital investment for the plant and the manufacturing and total costs of the product at each location, considering the applicable variations. A serious limitation to all such preliminary cost studies is the difficulty of projecting cost estimates into the future, involving development of new material sources, shifts in population and markets, and the advent of new transportation facilities, services, processes, and production. A knowledge of trends is essential for proper plant-location cost studies.

Weighted Scores

Another procedure of comparative location evaluation is that of weighted scores. The essential feature here is that the various locational cost factors are assigned weights proportionate to their assumed relative importance. Thus, for example, labor costs may be weighted 250, fuel costs 330, and power 100, with other factors bringing the total weight to 1,000. The appraisal of locations involves scoring each location with regard to each factor. The weighted average for each location constitutes the score, with the place scoring highest being presumably preferred.

This method permits intangibles to be evaluated and yet gives a definite numerical answer. It should be recognized, however, that it shares the limitations of the cost-comparison procedure.

Sources of Information

Essential information required for location study is determined mainly by the requirements of the industry and process in question. This will generally consist primarily of facts about the supply of materials, labor, power, transportation facilities, and markets, as well as information on the cost of sites, taxation, etc. For particular operations, important information may include climate, topography, and other factors, for ex-

ample, ones which will determine the type of foundations and buildings.

Information useful in determining costs at a location thus covers a great variety of subjects and is obviously widely scattered among many sources. Reference sources may be classified for convenience as public or private; they vary in scope from material covering the whole United States to local data. Since no single body, public or private, has the primary responsibility of compiling information useful to industrial location, the manufacturer must determine what is needed and where to find it.

Impartial information valuable to location studies is provided by many Federal, state, and local government departments and special agencies. For example, the U.S. Department of Labor compiles and publishes wage-and-hour statistics; the Department of Commerce regularly conducts a census of population, manufacturing, distribution, and business, and issues special industrial and commercial bulletins; the Department of the Interior prepares data and maps on topographic features, resources, and so forth. Among special agencies handling information useful to industrial locations are the Federal Trade Commission, the Federal Power Commission, and the Interstate Commerce Commission. Maps of the Coast and Geodetic Survey, Geological Survey, Bureau of Plant Industry and Soils, Public Roads Administration, Weather Bureau, etc., are particularly useful. Regional and state agencies furnish details which supplement information compiled by the Federal government and cover additional subjects as well. State planning boards, for example, have assembled information on resources and industrial opportunities in their areas and have made special studies of unemployment, skilled- and unskilled-labor supply, wage scales, cost and location of factory sites, and location of vacant buildings available for industrial occupancy. Taxation and laws affecting industrial operations are

among the items covered particularly by local units of government.[2]

Private agencies handling information important to location studies include many railroad and power companies, which benefit directly from the placing of industries on their lines and maintain departments to aid industries seeking spots for new plants or expansion of existing facilities. Both the railroads and the power companies, through their close contacts with industry, have a valuable fund of information—a fund which extends beyond the range of their immediate activities.

Table 57. Check List for Cost Factors in Plant Locations

Markets:
- *A.* Nearness to markets
- *B.* Nearness to distributors
- *C.* Nearness to export facilities
- *D.* Trading area
- *E.* Extent of market
- *F.* Nature of market
  1. Single buyers or scattered buyers
  2. Industrial and institutional
- *G.* Ease of making contact with brokers, agents, export middlemen
- *H.* Delivered-to-customers cost of product

Raw materials:
- *A.* Mineral resources
- *B.* Natural resources
- *C.* Agricultural crops
- *D.* Timber resources
- *E.* Location of raw materials
- *F.* Location in relation to suppliers
- *G.* Availability of subcontractors if required
- *H.* Availability of shipping and packaging materials

Labor:
- *A.* Wage rates
- *B.* Minimum-wage laws

Table 57. Check List for Cost Factors in Plant Locations (*Continued*)

- *C.* Type of labor
  1. Literacy rate
  2. Availability of management personnel
  3. Efficiency of labor
  4. Native skills
  5. Pride in craftsmanship of labor
  6. Unskilled-labor resources
  7. Nationality
  8. Predominant foreign-born nationalities
  9. Sex
  10. Skilled-labor resources
- *D.* Employment trends
- *E.* Trends in rate of production
- *F.* Labor laws
- *G.* Unions
- *H.* Labor-dispute record
- *I.* Cost of training new workers if already established
- *J.* Absenteeism rates
- *K.* Migratory trends

Power and utilities:

- *A.* Power resources
- *B.* Power rates
- *C.* Fuel resources
- *D.* Electric service
  1. Off-peak power costs
  2. Phase
  3. Power factor
  4. Transmission lines
  5. Power voltage
  6. Power current available
  7. Power frequency
- *E.* Gas service
- *F.* Utility rates
- *G.* Water power
- *H.* Coal
- *I.* Oil
- *J.* Quality of fuel
- *K.* Extent of fuel supply

Table 57. Check List for Cost Factors in Plant Locations (*Continued*)

Water:
- *A.* Water supply, type, ease of obtaining
- *B.* Water, chemical analysis
- *C.* Water rates or cost
- *D.* Water, bacterial analysis
- *E.* Water for
  1. Cooling
  2. Boiler feed
  3. Process
  4. Drinking

Transportation:
- *A.* Transportation facilities
  1. Air transportation
  2. Land transportation
  3. Water transportation
  4. Barge service
  5. Freight rates
  6. Port facilities
  7. Railroad-switching facilities
  8. Freight-train service
  9. Collection and delivery service
  10. Consolidated l.c.l. service
  11. Express service
  12. Air-freight service
  13. Tugboat service
  14. Motor-truck service
- *B.* Sidetrack facilities
- *C.* In-transit privileges
- *D.* Cost of extra trackage
- *E.* Laws affecting transportation
- *F.* Pipelines
- *G.* Demurrage charges
- *H.* Nearness to trunk highways
- *I.* Cost of wharf or dock (for water-front site)
- *J.* Nearness to trunk rail lines
- *K.* Trunk-line connections
- *L.* Interruptions

Table 57. Check List for Cost Factors in Plant Locations (*Continued*)

Taxes:
- *A.* Property tax
- *B.* Corporation tax
- *C.* Workmen's compensation
- *D.* Unemployment compensation
- *E.* Use tax
- *F.* Sales tax
- *G.* Real-property tax
- *H.* Unemployment-insurance tax
- *I.* License taxes
- *J.* Tax or rent concessions offered
- *K.* Tax trends

Insurance rates

Waste disposal:
- *A.* Ease of sale of waste products for profitable use
- *B.* Drainage
- *C.* Stream-pollution laws
- *D.* Waste-disposal laws
- *E.* Smoke-nuisance laws
- *F.* Odor-nuisance laws

Site and buildings:
- *A.* Usefulness of existing buildings
- *B.* Real-estate costs: lease and purchases
- *C.* Foundation conditions of soil
  1. Bedrock levels
  2. Water level
  3. Chemical features
  4. Objectionable soil pests
- *D.* Soil conditions
- *E.* Topography
  1. Drainage
  2. Contours
  3. Nearness to flowing water
  4. Grading required
- *F.* Real-estate assessments
- *G.* Building codes
- *H.* Cost of plant erection

Table 57. Check List for Cost Factors in Plant Locations (*Continued*)

Climate:
- *A.* Elevation
- *B.* Humidity
- *C.* Precipitation
- *D.* Temperature
- *E.* Natural-disaster frequency

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9. THE RELATIVE IMPORTANCE OF THE COMPONENTS OF COST

In the first five chapters of this book many factors from which the components of capital investment, manufacturing cost, and general expense can be ascertained were discussed. In order to avoid undue effort in preparing an estimate, it is important that the relative part each component plays in the total be known. Furthermore, since an estimate is only as strong as its weakest link, it is necessary to evaluate most accurately the items of most consequence. For example, it is pointless to determine carefully a component which is at most 5 per cent of the total cost and then make a gross approximation of an item representing one-half of the total.

The reader should be cautioned that we are discussing *average conditions* in this chapter and that in any specific case considerable variation may be found from the values portrayed herein.

FIXED CAPITAL AND WORKING CAPITAL

Table 58 shows a typical analysis of capital investment expressed as percentages of fixed-capital cost. It will be noted that the largest single item is purchased equipment. Furthermore, inasmuch as most of the remaining items of physical-plant cost or fixed-capital cost may be estimated, by certain of the methods discussed, as percentages of the purchased-

equipment value, the importance of properly determining the equipment cost is emphasized.

Table 58. Typical Analysis of Capital Investment

Type of capital investment	*Percentage of fixed capital*
Purchased equipment	25
Installation	11
Piping	10
Instrumentation	2
Insulation	2
Electrical	3
Buildings	8
Land and yard improvements	2
Utilities	9
Physical-plant cost	72
Engineering and construction	14
Direct plant cost	86
Contractor's fee	4
Contingency	10
Fixed capital	100
Working capital	15
Capital investment	115

When individual items of physical-plant cost are calculated, it will be noted that installation, piping, buildings, and utilities are second to equipment in importance. Such components as instrumentation, insulation, electrical auxiliaries, land, and yard improvements are collectively and individually of minor consequence in the estimate.

Engineering and construction expense is generally a sizable item. Since, however, it is generally calculated as a fraction of physical-plant cost, this further emphasizes the controlling

influence of the items already discussed. Of lesser importance individually are the contractor's fee and the contingency; since these too are usually estimated from prior subtotals, the relative effect of the major components of physical-plant cost is further strengthened.

MANUFACTURING COST AND GENERAL EXPENSE

Table 59 shows an average breakdown of manufacturing cost and general expense as percentages of manufacturing cost. By far the most important item is raw-material expense. Thus it is obvious how important consumption, prices, and yields of materials can be in the ultimate manufacturing cost. Labor is the component of immediate secondary magnitude. This is increased by the fact that payroll overhead and plant overhead are almost always calculated as fractions of labor expense and that laboratory charges and supervision may be estimated similarly if one so chooses.

Depreciation, property taxes, insurance, and sometimes maintenance and plant supplies are estimated from the fixed-capital investment. Individually these are small in the manufacturing cost, but together they can represent a sizable total. While the relative magnitude of the capital cost is important in determining these items, it is not necessary to employ the more detailed capital-estimation procedures.

Utilities taken collectively represent an amount of relative importance in a manufacturing cost.

Royalties on the average are small but should be carefully considered when large. Similarly, shipping costs are usually minor. Packaging expense is usually small since the chemical industry is primarily a bulk supplier; however, in particular phases of the industry packaging may prove to be of major importance, as indicated in Chap. 4.

General expenses are a sizable portion of total cost. Since

these may be estimated as percentages of manufacturing cost, the accurate estimation of the components of this cost is further emphasized.

Table 59. Typical Analysis of Total Cost

	Percentage of manufacturing cost	
Raw materials	40	
Labor	15	
Supervision	2	
Maintenance	3	
Plant supplies	1	
Royalties and patents	2	
Utilities	10	
Direct manufacturing cost		73
Payroll overhead	3	
Laboratory	3	
Plant overhead	12	
Packaging	1	
Shipping	1	
Indirect manufacturing cost		20
Depreciation	5	
Property taxes	1	
Insurance	1	
Fixed manufacturing cost		7
Manufacturing cost		100
Administration	5	
Sales	15	
Research	6	
Finance	2	
General expenses		28
Total cost		128

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10. ECONOMIC EVALUATION

MANAGEMENT is constantly in search of ways and means of enhancing and protecting a company's position. In the quest for growth and stability, the company endeavors to find new products for markets it already serves, new products which utilize available materials, and processes to complement or fully utilize existing facilities. Integration and diversification are of prime consideration for any company. In addition, management action must reflect and anticipate any variations in markets, changes in buying habits and preferences of customers, new product and manufacturing developments by competitors, and changes in the earnings and earning ratios of the company.

Definition of Economic Evaluation

Improvement of a company's position is a constant problem. In the fast-moving chemical industry, where obsolescence of products takes place rapidly, current prosperity and profits are no assurance of continued success.[1, 8, 15]

Business decisions on new projects are no longer based upon executive intuition or hunches. Management relies extensively upon information supplied by specialized employees in order properly to evaluate the technical and economic feasibility of any project under consideration or even under development.

The technique of economic evaluation is simply a screening process by which economically unsound projects or courses of action are eliminated from further consideration. Since it is

recognized that many more ideas are available for experimentation than there are funds, personnel, or facilities to exploit them, such a procedure enables a firm to concentrate its efforts on those prospects reflecting the best potentials.

Purpose of Economic Evaluation

Chemical product and process development is a calculated risk. To minimize such risk, economic evaluation is employed by management to help answer three basic questions which arise.[3-5, 10-12]

1. Should the project be undertaken at all? The potential profitability, the inherent risk, the prospects of alternative projects, the enhancement of existing product line, and over-all company policies must be taken into consideration.
2. Should the project be undertaken at this time? Trends in markets, the company's financial resources, and the economy in relation to expansion must be explored.
3. Is this the proper method for the project? Alternative technical and economic procedures as well as different raw materials and intermediates must be studied.

Management has the responsibility of trying to screen out those projects which it believes to be unsound or least attractive. It cannot afford to waste money on a project which may turn out to be useless. The many alternative projects which are always available to a company predicate the use of a screening procedure, not to locate a foolproof venture, but to try to select the best possible project. Even back in 1912, Whiting, the inventor of the Whiting electrolytic cell, made the following observation:

> From a practical standpoint, it is useless to spend time and money on a process not commercially sound, but this is being done constantly by inventors all over the world. I have personally known several cases where men have

spent years developing a secret process, only to find in the end that the market conditions were unsound, a fact easily ascertainable in the beginning.[16]

Despite the fact that the technique of evaluation has improved and advanced since then, cases of poor and misdirected efforts still develop.

Types of Projects

Although economic evaluation can occur at any stage of a product's development, types of projects may be subdivided into three basic categories:

1. Completely new products.
2. Established products, new to the company.
3. New processes or techniques for established products.

In normal industrial practice, the number of projects based on completely new products is but a small fraction of the total number of projects which receive consideration. The approach employed in evaluation will differ somewhat for each of the three cases above.

1. For a completely new product, the company must base its evaluation in large part upon unknown factors and educated guesses.
2. In the case of established products new to the company, markets and technical aspects are better known and can be evaluated with greater certainty.
3. In the case of a new process or technique for producing an old product, market considerations are of no concern. Furthermore, the existing process offers a rule for measuring the attractiveness of the proposed change.

Periodic Evaluation

Economic evaluation of a project is a continuous procedure. It should be initiated with the very inception of a project and

continued through its life until the project is proved successful or abandoned. There are a number of important times when a thorough evaluation may be necessary. Such special points of development may occur after each of the following stages:[8,15]

1. Idea formulation.
2. Laboratory research.
3. Pilot plant.
4. Plant design.

At each stage of development, more detailed examinations are possible, since more data become available. Each successive evaluation must be more precise, because each one of the steps of development usually is more expensive to conduct than the previous one. While conditions and information may change during the over-all evaluation of a project, the important point to remember is that evaluation is a continuous process, since stopping a project at the proper time or guiding it into alternative channels may save the company both money and resources.

An idea of the importance of proper evaluation at the various stages of development may be obtained from the following cost analysis on the relative expense incurred at various phases of product development: [19]

Table 60. Analysis of Cost of Product Development

Phase of development	*Percentage of cost of project*
Laboratory research.....	10
Pilot-plant development.....	25
Plant design and erection.....	65

Idea Formulation. The initial evaluation of a project should begin upon development of the idea. Such an analysis will indicate the potentialities of the project and may even reflect

possible shortcomings. By following such a procedure on a routine basis, research effort will be placed upon the most promising prospects while those certain to fail will be dropped before time and effort is wasted upon them. While little factual data may be available at this stage upon which to base an evaluation, it is important to avoid undue conservatism in cost estimating. Research at this point is relatively inexpensive, and to condemn a project by overconservative estimating may often eliminate perfectly sound projects from consideration and even deprive the company of eventual added revenue. The more simplified methods of estimating will prove sufficient in most cases for idea screening.

Laboratory Research. A secondary study may be conducted after termination of the laboratory work, or if the project is involved, at several stages of completion. The object is basically to ascertain the advisability of continuing the project into further development and to indicate the feasibility of different courses of action. Considerably more information will be available at this stage upon which to base an estimate. Material balances and yields will have been determined. Some of the optimism employed in appraising the idea should be tempered, although not unduly so. Estimating methods which are in line with the amount of information available should be employed; in most cases this will dictate the use of intermediate procedures.

Pilot Plant. At the third stage in evaluation, all research and pilot-plant work have been completed. Material balances and yields have been established in equipment which can be realistically scaled up to plant size. Sound unit operations have been developed. All assumptions made in prior estimates should have been proved or altered by experimentation. An evaluation at the completion of pilot-plant operations is necessary to determine the advisability of designing a commercial plant for manufacture of the product. Realistic estimates should be secured, insofar as completion of the experimental

data has replaced the need for optimism. Some of the more detailed estimating procedures should be employed at this stage of development.

Plant Design. The final economic evaluation is conducted after design of the manufacturing plant has been completed. All prior evaluations should be carefully reviewed and realistically altered in view of the completed plant design. Short-cut estimating procedures should be avoided. A project should be thoughtfully and fairly scrutinized at this stage before the company is committed to a construction program.

Factors Determined

In screening projects, a company employs both technical and economic information. The controlling factor in the success of any business enterprise is its ability to earn a profit. While a project may meet technical requirements, its ultimate success will be indicated only after economic analysis. Economic evaluation at any stage in development is designed to determine the following: [2, 6, 7, 9, 13, 14, 17, 18]

1. Capital investment.
2. Manufacturing and total cost.
3. Sales price.
4. Return on investment.

Considerable effort, requiring the cooperation of many groups, must go into the preparation of sufficient data from which these items can be determined. The extent to which such information is investigated, and the methods used, will depend upon the project's stage of development.

Capital Investment. The fixed-capital investment required for the erection of manufacturing facilities must be estimated from flow sheets and design data. Working-capital estimates must be based upon the conditions involved.

Manufacturing and Total Cost. The manufacturing costs for operating the plant must be determined from material bal-

ances, utility consumption, labor requirements, and equipment utilization. A thorough examination of the raw-material picture is vital before one can assume adequate supplies at satisfactory prices. The components of general expense must be ascertained and added to the manufacturing cost to give the total cost. Sales expense should be based upon the distribution and selling mechanisms to be employed. Administrative, research, and financial expenses are assayed.

Sales Price. The price at which the product is to be sold should be selected. A market analysis must be made to ascertain the applications of the product, the markets, and the competition. The fraction of the market available to the company should be determined, and the relationship between sales price and sales volume established.

Return on Investment. From the sales price and total cost, the profit can be calculated. This profit should be expressed in some relationship to the investment and assayed with regard to the risk involved.

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NOMENCLATURE

a = material index
a_c = annual total cost at r_a
a_n = annual gross return at r_a to maintain the per cent return on investment
a_s = annual sales value at r_a
B = amount of outstanding borrowed capital
b = labor index
C_a = annual total cost at maximum production
c_a = capacity of equipment a
c_b = capacity of equipment b
D = pay-out time in years
d = number of years at which cash position is measured
E = purchased-equipment cost
E_a = purchased cost of equipment a
E_b = purchased cost of equipment b
E_x = purchased cost of equipment for year x
E_y = purchased cost of equipment for year y
F_a = annual fixed expense at maximum production
G = general expense per unit of production
H = cash position
h = container and shipping cost per unit of production
I_F = fixed-capital investment
I_{Fa} = fixed-capital investment of plant a
I_{Fb} = fixed-capital investment of plant b
I_W = working-capital investment
I_T = total capital investment
i_F = fixed-capital per unit of annual productive capacity
K = maintenance cost per year
k = man-hours of labor per unit of production
L = Lang's factor
M = manufacturing cost per unit of production

m = raw material cost per unit of production
N_a = annual gross return
N_x = index value for year x
N_y = index value for year y
P_a = profit after taxes, per unit of production
P_b = profit before taxes, per unit of production
P_k = minimum acceptable per cent return on investment before taxes, expressed as a decimal
P_{ra} = per cent return on investment after taxes, expressed as a decimal
P_{rb} = per cent return on investment before taxes, expressed as a decimal
P_{sa} = per cent profit on sales after taxes, expressed as a decimal
P_{sb} = per cent return on sales before taxes, expressed as a decimal
Q = production cycle, in months
R_a = annual regulated expense at maximum production
r_a = annual production rate
r_m = monthly production rate
r_{ma} = monthly production rate of plant a
r_{mb} = monthly production rate of plant b
S = sales value per unit of production
S_a = annual sales value at maximum production
T = turnover ratio
t = income-tax rate, expressed as a decimal
u = utility cost per unit of production
V = venture profit per unit of production
V_a = annual variable expense at maximum production
X = kilowatthours of electricity used per year
y = cost per man-hour with overhead
$\tilde{\sim}$ = annual maximum production

SAMPLE PROBLEMS

1. What is the fixed-capital investment for a fluid-process plant in which the purchased cost of the equipment is $435,000?

Solution:

$$I_F = EL$$

$$L = 4.74$$

$$I_F = 435{,}000 \times 4.74$$

$$= \$2{,}062{,}000$$

2. The fixed-capital investment for a 250,000-lb-per-month chemical plant is $800,000. What would be the fixed-capital investment for a similar plant of 500,000-lb-per-month output?

Solution:

$$I_{Fb} = I_{Fa}\left(\frac{r_{mb}}{r_{ma}}\right)^{0.7}$$

$$= 800{,}000\left(\frac{500{,}000}{250{,}000}\right)^{0.7}$$

$$= \$1{,}300{,}000$$

3. What is the fixed-capital cost of a synthetic-methanol plant with an annual production of 10,000,000 gal per year?

Solution:

$$I_F = i_F r_a$$

$$i_F = \$270$$

$$I_F = \frac{270 \times 10{,}000{,}000 \times 8.33 \times 0.792}{2{,}000}$$

$$= \$8{,}900{,}000$$

4. What is the fixed-capital investment of a 10,000,000-lb-per-year ethylene glycol plant?

Solution:

$$I_F = \frac{Sr_a}{T}$$

$$S = \$0.13/\text{lb}$$

$$T = 1.11$$

$$I_F = \frac{0.13 \times 10{,}000{,}000}{1.11}$$

$$= \$1{,}170{,}000$$

5. The unit manufacturing cost of a 200,000-gal-per-month chemical plant is \$0.70 per gallon, of which \$0.28 per gallon represents the cost of raw materials. With a production cycle of ½ month, what is the required working capital?

Solution:

$$I_W = r_m(m + 0.5MQ + 4M)$$

$$= 200{,}000(0.28 + 0.5 \times 0.70 \times 0.5 + 4 \times 0.70)$$

$$= \$651{,}000$$

6. The purchase price of a 500-gal reactor in 1950 was \$6,000.

a. What would be the purchased cost of such a reactor in 1953?

b. What would be the price of a 1,000-gal reactor in 1953?

Solution:

a.

$$E_x = E_y \frac{N_x}{N_y}$$

Use Marshall and Stevens process-industry indices.

$$1950 \text{ index} = 167$$

$$1953 \text{ index} = 181$$

$$E_x = 6{,}000 \frac{181}{167}$$

$$= \$6{,}500$$

b.

$$E_b = E_a \left(\frac{C_b}{C_a}\right)^{0.6}$$

$$= 6{,}500 \left(\frac{1{,}000}{500}\right)^{0.6}$$

$$= \$9{,}850$$

7. A simple crystallization unit consists of the following process equipment:

3 1,000-gal agitated steel tanks
1 200-sq-ft cast-iron plate and frame filter
1 1,000-sq-ft steel horizontal-tube evaporator
1 300-ft steel mechanical crystallizer
1 200-sq-ft steel atmospheric tray dryer
2 2,000-gal pine storage tanks
1 42-in. steel batch top-suspended centrifugal

The equipment will be housed indoors and will require a minimum of additional utility services. Little instrumentation will be employed.

a. What is the purchased-equipment cost?
b. What is the physical-plant cost?
c. What is the direct plant cost?
d. What is the fixed-capital investment?

Solution:

a.

	Cost item	*Cost*
3	1,000-gal agitated steel tanks	$ 9,300
1	200-sq-ft cast-iron plate and frame filter	2,600
1	1,000-sq-ft steel horizontal-tube evaporator	22,000
1	300-ft steel mechanical crystallizer	25,000
1	200-sq-ft steel atmospheric tray dryer	2,500
2	2,000-gal pine storage tanks	760
1	42-in. steel batch top-suspended centrifugal	5,600
	Purchased-equipment cost	$ 67,760

b.

Purchased-equipment cost	$ 67,760
Equipment installation, at 43% of purchased-equipment cost	29,100
Piping, at 36%	24,400
Instrumentation at 5%	3,400
Insulation, at 8%	5,420
Electrical, at 15%	9,480
Building, at 80%	54,200
Land and yard improvements, at 12%	8,140
Utilities, at 25%	16,930
Physical-plant cost	$218,830

c.

Physical-plant cost	$218,830
Engineering and construction, at 30% of physical-plant cost	65,800
Contractor's fee, at 7%	15,400
Direct plant cost	$300,030

d.

Direct plant cost	$300,030
Contingency, at 10% of direct plant cost	30,003
Fixed-capital investment	$330,033

8. It is desired to be able to pump 3,000 lb per hour of a liquid whose density is 50 lb per cu ft through 100 ft of duriron pipe of the most economic pipe diameter. The line will contain 15 fittings and 3 valves.

a. What pipe diameter should be employed?

b. What will be the installed cost of such a line?

c. If the line is insulated with $1\frac{1}{2}$-in. 85 per cent magnesia what will be the insulation cost?

Solution:

a. Use 1-in.-diameter pipe.

b.

Cost item	*Cost*
Pipe, 100 ft at $4.20	$ 420
Installation, at 30%	126
Fittings, 15 at $11	165
Installation, at 125%	206
Valves, 3 at $42	126
Installation, at 25%	32
Total piping cost	$1,075

c.

Insulation, 100 ft at $0.80	$ 80
Installation, at 200%	160
Total insulation cost	$ 240

9. A one-story 20-ft-high warehouse 100 ft by 60 ft in size is to be erected on 60 piles and will be constructed of a reinforced-concrete floor, cinder-block walls, and a corrugated-steel roof. What will be the cost of the building complete with sprinklers, heating, and lights?

Solution:

Cost item	*Cost*
Piles, 60 at $100	$ 6,000
Reinforced-concrete floor, 6,000 sq ft at $0.75	4,500
Cinder-block walls, 6,400 sq ft at $1.30	8,300
Corrugated-steel roof, 6,000 sq ft at $0.70	5,600
Sprinklers, 6,000 sq ft at $0.50	3,000
Heating, 6,000 sq ft at $1	6,000
Lighting, 6,000 sq ft at $0.50	3,000
Building cost	$36,400

10. It has been determined that a new process installation will require 10,000 lb per hr of steam, 1,000 kva of electricity, and 30,000 gph of tower water. What will be the installed cost of these utilities?

Solution:

Cost item	*Cost*
Steam, 10,000 lb/hr at $5	$ 50,000
Electricity, 1,000 kva at $200	200,000
Tower water, 30,000 gph at $0.50	15,000
Utility cost	$265,000

11. What are the manpower requirements for a 40-ton-per-day production by a process consisting of filtration, concentration, crystallization, centrifuging, and drying?

Solution:

Number of process steps = 5

Capacity/day = 40 tons

Manpower = 5 × 1 = 5 man-hr/ton

12. It takes 20 men per shift to operate a complex $2,200,000 plant on a continuous basis to produce 8,000,000 lb per year of a product. Raw materials will cost $0.16 per pound of product. Utility needs are as follows: 100-psi steam, 50 lb per pound; purchased electric power, 0.5 kwhr per pound; and filtered water, 10 gal per pound. The product will be packaged in 50-lb bags.

a. What is the direct manufacturing cost?

b. What is the indirect manufacturing cost?

c. What is the fixed manufacturing cost?

d. What is the manufacturing cost?

Solution:

a.

Cost item	*Cost per lb*
Raw materials	$0.1600
Labor, 175,000 man-hr/year × $1.70/hr, at production of 8,000,000 lb/year	0.0372
Supervision = 25% of labor	0.0094
Maintenance, ($2,200,000 × 7%)/8,000,000	0.0193
Plant supplies, $0.0193 × 15%	0.0029
Utilities, 100-psi steam, 50 lb at $0.50/1,000 lb	0.0250
Purchased power, 0.5 kwhr at $0.015/kwhr	0.0075
Filtered water, 10 gal at $0.15/1,000 gal	0.0015
Direct manufacturing cost	$0.2628

b.

Payroll overhead, \$0.0372 × 17%	0.0063
Laboratory, \$0.0372 × 15%	0.0056
Plant overhead, \$0.0372 × 100%	0.0372
Package, at \$0.10 per 50-lb bag	0.0020
Indirect manufacturing cost	\$0.0511

c.

Depreciation, (\$2,200,000 × 10%)/8,000,000	0.0275
Property taxes, (\$2,200,000 × 1.5%)/8,000,000	0.0041
Insurance, (\$2,200,000 × 1%)/8,000,000	0.0028
Fixed manufacturing cost	\$0.0344

d.

Direct manufacturing cost	\$0.2628
Indirect manufacturing cost	0.0511
Fixed manufacturing cost	0.0344
Manufacturing cost	\$0.3483

13. What is the annual maintenance expense on a unit consisting of the items in the left-hand column below?

Solution:

Equipment	*Cost*
1 20-in. bottom-driven centrifuge	\$ 200
3 2,000-gal batch crystallizers	600
1 100-sq-ft atmospheric tray dryer	400
1 two-stage evaporator, 1,000 sq ft/stage	1,000
3 30-gpm centrifugal pumps	300
4 1,000-gal steel tanks	48
200 ft of 2-in. steel pipe	40
200 ft of 1-in. steel pipe	20
150 ft of 4-in. cast-iron pipe	30
Annual maintenance expense	\$2,638

14. A plant has been erected at a cost of \$600,000 to produce 1,000,000 lb of a product annually. Raw materials for the product cost \$0.35 per pound, utilities \$0.12 per pound, and packaging \$0.05 per pound. Manpower requirements are 0.25 man-hr per pound of product. What is the manufacturing cost?

Solution:

$$M = m + u + h + 3.55k + \frac{0.21I_F}{r_a}$$

$$= 0.35 + 0.12 + 0.05 + 3.55 \times 0.25 + \frac{0.21 \times 600{,}000}{1{,}000{,}000}$$

$$= \$1.54/\text{lb}$$

15. What is the unit general expense of an established coal-tar product to be sold at \$0.16 per pound in large volumes to other manufacturers?

Solution:

$$\text{Administrative expense} = 0.025 \times 0.16 = \$0.004/\text{lb}$$

$$\text{Sales expenses} = 0.02 \times 0.16 = \$0.0032/\text{lb}$$

$$\text{Research expenses} = 0.007 \times 0.16 = \$0.0011/\text{lb}$$

$$\text{General expense} = 0.004 + 0.0032 + 0.0011 = \$0.0083/\text{lb}$$

16. What is the unit general expense on a product sold for \$0.18 per pound and manufactured at a rate of 500,000 lb per year in a plant upon which \$60,000 of the required capital investment was borrowed?

Solution:

$$G = 0.13S + \frac{0.03B}{r_a}$$

$$= 0.13 \times 0.18 + \frac{0.03 \times 60{,}000}{500{,}000}$$

$$= \$0.027/\text{lb}$$

17. Market studies have indicated sales, at \$0.40 per pound, of 8,000,000 lb per year of a new low-risk industrial chemical. The fixed-capital investment for such a plant has been estimated at \$2,000,000. The manufacturing cost of the product has been ascertained at \$0.22 per pound. General expenses of \$0.08 per pound have been found to apply.

a. What is the unit profit before taxes?

b. What is the per cent profit before taxes on sales?

c. What is the per cent return before taxes on the investment?

d. What is the minimum sales price which should be charged commensurate with the risk involved?

e. What is the unit venture profit expected?

f. What is the pay-out time on the investment?

g. What will be the cash position after 4 years?

Solution:

a.
$$P_b = S - M - G$$
$$= 0.40 - 0.22 - 0.08$$
$$= \$0.10/\text{lb}$$

b.
$$P_{sb} = \frac{P_b}{S}$$
$$= \frac{0.10}{0.40}$$
$$= 25\%$$

c.
$$P_{rb} = \frac{P_b r_a}{I_F}$$
$$= \frac{0.10 \times 8{,}000{,}000}{2{,}000{,}000}$$
$$= 40\%$$

d. $$S = \frac{I_F P_k}{r_a} + M + G$$

$$P_k = 11\%$$

$$S = \frac{2{,}000{,}000 \times 0.11}{8{,}000{,}000} + 0.22 + 0.08$$

$$= \$0.328/\text{lb}$$

e. $$V = P_b - \frac{I_F P_k}{r_a}$$

$$= 0.10 - \frac{2{,}000{,}000 \times 0.11}{8{,}000{,}000}$$

$$= \$0.072/\text{lb}$$

f. $$D = \frac{I_F}{P_b r_a + 0.1 I_F}$$

$$= \frac{2{,}000{,}000}{0.10 \times 8{,}000{,}000 + 0.1 \times 2{,}000{,}000}$$

$$= 2 \text{ years}$$

g. $$H = d(P_b r_a + 0.1 I_F - P_b r_a t) - I_F$$

$$= 4(0.10 \times 8{,}000{,}000 + 0.1 \times 2{,}000{,}000 - 0.10 \times 8{,}000{,}000 \times 0.52) - 2{,}000{,}000$$

$$= \$336{,}000$$

18. A market survey has indicated the existence of a potential sales volume on a new product at the noted prices:

Market, lb/year	*Sale price per lb*
200,000	\$0.85
500,000	0.85
1,000,000	0.75
2,000,000	0.60

For a plant of 200,000-lb-per-year capacity, a fixed-capital-cost estimate has been prepared. This has been analyzed to ascertain the cost of those components which would be increased in number and those which would be increased in size in a plant of greater capacity.

Units varying by number	$100,000
Units varying by size	152,000
Fixed capital	$252,000

Similarly, manufacturing-cost and general-expense estimates have been determined for the plant of 200,000 lb annual capacity. The manufacturing-cost estimate has been analyzed to determine the expenses on units varying by number and those on units varying by size in larger plants.

Cost item	*Cost per lb*
Raw materials, utilities, packaging	$0.200
Fixed expenses and maintenance on units varying by number	0.080
Fixed expenses and maintenance on units varying by size	0.075
Labor and proportional expenses on units varying by number	0.160
Labor and proportional expenses on units varying by size	0.071
Manufacturing cost	$0.586
General expenses	0.059
Total cost	$0.645

Management has declared that a 20 per cent return on the investment before taxes must be earned in view of the relative risk involved.

a. What will be the fixed-capital costs of plants operating at maximum annual capacities of 500,000 lb, 1,000,000 lb, and 2,000,000 lb?

b. What is the unit manufacturing cost for each of the plant sizes considered?

c. What is the unit general expense at each of the plant sizes considered?

d. At which of the plant sizes considered will the maximum unit profit be secured?

e. At which of the plant sizes considered will the maximum annual profit be secured?

f. At which of the plant sizes considered will the maximum per cent return on the investment before taxes be secured?

Solution:

a. For those components of the capital cost which will vary by number, multiply that portion of the capital cost at the base size by the ratio of the larger size to the base size.

For those components of the capital cost which will vary by size,

	200,000 lb/year	500,000 lb/year	1,000,000 lb/year	2,000,000 lb/year
By number:				
Ratio.....	1	2.5	5	10
Capital cost....	$100,000	$250,000	$500,000	$1,000,000
By size:				
Ratio.....	1	$2.5^{0.6}$	$5^{0.6}$	$10^{0.6}$
Capital cost....	$152,000	$263,000	$400,000	$ 605,000
Total capital cost.....	$252,000	$513,000	$900,000	$1,605,000

multiply that portion of the capital cost at the base size by the ratio to the 0.6 power of the larger size to the base size.

b. Convert the base unit manufacturing cost to annual manufac-

turing expense. Multiply by the ratio to the proper exponential power of the larger size to the base size. Divide by the annual capacity to get the unit manufacturing cost.

	200,000 lb/year		500,000 lb/year
	Per lb	Annual	Per lb
Raw materials, etc.	\$0.200	\$40,000 × 2.5 = \$100,000	\$0.200
Fixed expenses, etc., units varying by number	0.080	16,000 × 2.5 = 40,000	0.080
Fixed expenses, etc., units varying by size	0.075	$15{,}000 \times 2.5^{0.6}$ = 26,000	0.052
Labor, etc., units varying by number	0.160	32,000 × 2.5 = 80,000	0.160
Labor, etc., units varying by size	0.071	$14{,}200 \times 2.5^{0.25}$ = 17,900	0.036
Manufacturing cost	\$0.586		\$0.528

Following the same procedure, the following values for manufacturing cost are secured:

	200,000 lb/year	500,000 lb/year	1,000,000 lb/year	2,000,000 lb/year
Raw materials, etc.	$0.200/lb	$0.200/lb	$0.200/lb	$0.200/lb
Fixed expenses, etc., units varying by number	0.080	0.080	0.080	0.080
Fixed expenses, etc., units varying by size	0.075	0.052	0.040	0.030
Labor, etc., units varying by number	0.160	0.160	0.160	0.160
Labor, etc., units varying by size	0.071	0.036	0.021	0.013
Manufacturing cost	$0.586/lb	$0.528/lb	$0.501/lb	$0.483/lb

c. General expense = $0.059/$0.586 = 10% of manufacturing cost.

Capacity, lb/year	*General expense per lb*
200,000	$0.059
500,000	0.053
1,000,000	0.050
2,000,000	0.048

d.

	200,000 lb/year	500,000 lb/year	1,000,000 lb/year	2,000,000 lb/year
Sale price...	$ 0.85/lb	$ 0.85/lb	$ 0.75/lb	$ 0.60/lb
Manufacturing cost...	−0.586	−0.528	−0.501	−0.483
General expense.....	−0.059	−0.053	−0.050	−0.048
Profit.....	$ 0.205/lb	$ 0.269/lb	$ 0.199/lb	$ 0.069/lb

Maximum unit profit is at a capacity of 500,000 lb per year.

e.

Capacity, lb/year	*Annual profit*
200,000	$ 41,000
500,000	134,500
1,000,000	199,000
2,000,000	138,000

Maximum annual profit is at a capacity of 1,000,000 lb per year.

f.

$$P_{rb} = \frac{P_b r_a}{I_F}$$

	200,000 lb/year	500,000 lb/year	1,000,000 lb/year	2,000,000 lb/year
Annual profit.....	$ 41,000	$134,500	$199,000	$ 138,000
Capital.....	$252,000	$513,000	$900,000	$1,605,000
% return.....	16.3%	26.2%	22.1%	8.6%

Maximum per cent return is at a capacity of 500,000 lb per year.

19. Market studies have indicated a market of 6,000,000 gal per year of a product at a recommended price of \$1.30 per gallon. The total capital investment will be \$6,000,000, upon which a 20 per cent return before taxes is expected by management in view of the risk involved. Annual fixed expenses have been estimated at \$600,000. Regulated expenses at capacity operation are expected to run \$2,400,000 per year. Variable expense will be approximately \$0.60 per gallon.

a. At what production level will total cost break even with sales?

b. If the \$1.30-per-gallon price must be maintained, at what production level must operations be discontinued?

c. How much must the sales price be raised to realize the desired 20 per cent return on investment before taxes if production remains at the break-even level of 3,140,000 gal per year?

d. At what production level will the 20 per cent annual return be achieved employing a sales price of \$1.50 per gallon?

e. What will be the per cent return on investment at the 4,060,000-gal-per-year rate if the price is held at the recommended \$1.30-per-gallon level?

Solution:

a.
$$r_a = \frac{(F_a + 0.3R_a)Z}{S_a - V_a - 0.7R_a}$$
$$= \frac{(600{,}000 + 0.3 \times 2{,}400{,}000)6{,}000{,}000}{1.30 \times 6{,}000{,}000 - 0.60 \times 6{,}000{,}000 - 0.7 \times 2{,}400{,}000}$$
$$= 3{,}140{,}000 \text{ gal/year}$$

b.
$$r_a = \frac{0.3R_aZ}{S_a - V_a - 0.7R_a}$$
$$= \frac{0.3 \times 2{,}400{,}000 \times 6{,}000{,}000}{1.30 \times 6{,}000{,}000 - 0.60 \times 6{,}000{,}000 - 0.7 \times 2{,}400{,}000}$$
$$= 1{,}710{,}000 \text{ gal/year}$$

$$c.\quad \frac{S_a}{\mathcal{Z}} = \frac{V_a + 0.7R_a}{\mathcal{Z}} + \frac{F_a + 0.3R_a + P_{rb}I_T}{r_a}$$

$$= \frac{0.60 \times 6{,}000{,}000 + 0.7 \times 2{,}400{,}000}{6{,}000{,}000}$$

$$+ \frac{600{,}000 + 0.3 \times 2{,}400{,}000 + 0.20 \times 6{,}000{,}000}{3{,}140{,}000}$$

$$= \$1.68/\text{gal}$$

$$d.\quad r_a = \frac{(F_a + 0.3R_a + P_{rb}I_T)\mathcal{Z}}{(S_a/\mathcal{Z})\mathcal{Z} - V_a - 0.7R_a}$$

$$= \frac{(600{,}000 + 0.3 \times 2{,}400{,}000 + 0.20 \times 6{,}000{,}000)6{,}000{,}000}{1.50 \times 6{,}000{,}000 - 0.60 \times 6{,}000{,}000 - 0.7 \times 2{,}400{,}000}$$

$$= 4{,}060{,}000 \text{ gal/year}$$

$$e.\quad P_{rb} = \frac{(S_a/\mathcal{Z})\mathcal{Z} - V_a - 0.7R_a}{\mathcal{Z}I_T} r_a - \frac{F_a + 0.3R_a}{I_T}$$

$$= \frac{\left\{\begin{array}{l}(1.30 \times 6{,}000{,}000 - 0.60 \times 6{,}000{,}000\\ \quad - 0.7 \times 2{,}400{,}000)4{,}060{,}000\end{array}\right\}}{6{,}000{,}000 \times 6{,}000{,}000}$$

$$- \frac{600{,}000 + 0.3 \times 2{,}400{,}000}{6{,}000{,}000}$$

$$= 6.4\%$$

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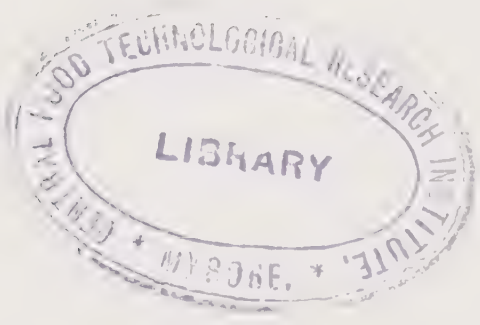
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